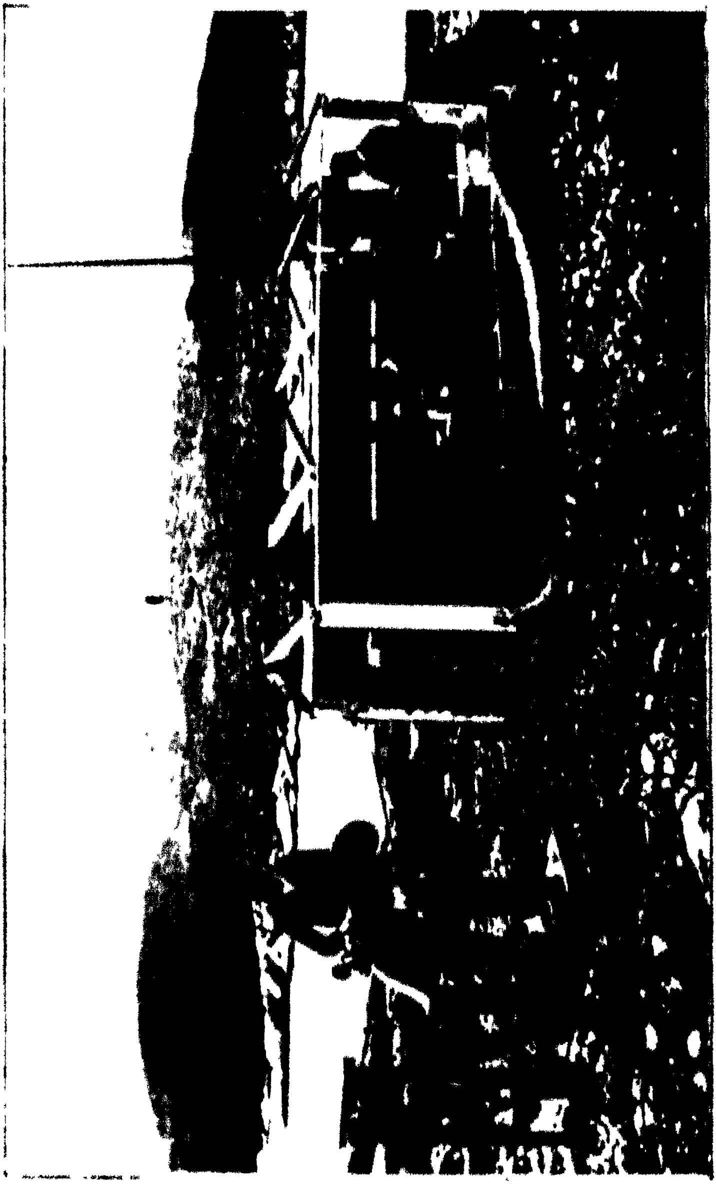
RECENT AND COMING ECLIPSES.

Frontispiece



RECENT AND COMING ECLIPSES

BEING NOTES ON THE TOTAL SOLAR ECLIPSES OF
1893, 1896, AND 1898.

BY

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PREFACE.

CONSIDERABLE interest in the phenomena presented by a total eclipse of the sun was awakened last year when one occurred almost at our doors—a thing which happens but rarely. Very many went to see it and more who stayed at home had their attention drawn to one of the most awe-inspiring sights it is given to man to witness. The recurrence of an eclipse next year in India in the cool season with almost a certainty of clear skies has sustained this general interest, and will doubtless attract numerous travellers to the best points of observation.

Since several important advances in our knowledge of the sun have recently been made by instruments more powerful than any used before, it has struck me that it might be well to bring together in book form some fugitive articles in *Nature* and elsewhere and other contributions of a more serious nature in the *Philosophical Transactions* which I have recently written concerning eclipse work.

I am the more inclined to do this as it gives me another opportunity of calling attention to the splendid assistance rendered by the officers and men of H.M.S. "Volage," last year, which established an important precedent for all succeeding similar endeavours.

I have to acknowledge my indebtedness to the Council of the Royal Society and to Messrs. Macmillan for permission to use many of the illustrations given in the volume.

NORMAN LOCKYER.

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South Kensington,
August, 1897.

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RECENT AND COMING ECLIPSES.

CHAPTER I.—ECLIPSE REVELATIONS AND THEIR USES.

THERE is no question that a total eclipse of our central luminary is one of the grandest and most awe-inspiring sights that it is given to man to witness; feelings of awe, mingled with wonder are at once appealed to by the attendant phenomena; and it is not surprising that in ancient times, when knowledge was less, and less widely spread, than it is now, superstition, fear, and dread put all other emotions in the shade.

There has been no total eclipse of the sun visible in Britain since 1715, nor will there be one for many years to come; those, therefore, who would witness one must go afield, sometimes very far afield; and this involves a considerable expenditure both of time and money, and often discomfort and risk to health. It was very fortunate, therefore, that in 1896 an eclipse was visible almost close at home, and that the arrangements made by many shipping companies, both British and foreign, secured all the comfort and all the delights of a yachting cruise at the best season of the year. Many thousands of persons, therefore, were induced to travel to Norway in the hope ot seeing the unaccustomed sight of the sun hid in "dire eclipse."

It is true that few were successful in their endeavours, but all the same there is no doubt that much general interest in all matters relating to eclipses was awakened.

It is not a little singular that a previous eclipse, which happened in Norway in 1851, may almost be reckoned the first in the series which has supplied us with the considerable contributions to our knowledge of the sun's nature which we now possess

It is now more than forty years since Professor Grant wrote as follows, and the experience of six eclipses tells me it is difficult to improve his description:—

"On no other occasion does the display of stupendous power in the economy of the physical universe exercise so subduing an influence over the mind, or produce so humiliating a conviction of the impotence of all human efforts to control the immutable laws of nature and arrest the course of events, as when the glorious orb of day, while riding in the heavens with unclouded splendour, begins to melt away from an unseen cause, and soon totally disappears, leaving the whole visible world wrapped in the sable gloom of nocturnal darkness. The scene is rendered still more impressive by the circumstances accompanying so remarkable an occurrence. The heavens assume an unnatural aspect, which excites a feeling of horror in the spectator, a livid hue is diffused over all terrestrial objects; plants close up their leaves as on the approach of night, the fowls betake themselves to their resting-places; the warbling of the grove is hushed in profound silence; in other words, universal nature seems to relax her energies, as if the pulse which stimulated her mighty movements had all at once stood still."

At the present day, an eclipse of the sun is looked forward to with the highest interest; not only is the sight truly weird beyond description to all onlookers, but men of science, aided by modern appliances, are enabled to make use of these few precious moments in unravelling many of the problems which can only be solved at such times.

But before I refer more especially to sights that are seen which help us in the elucidation of these problems, one word, to begin at the beginning, may be said with regard to the origin of the eclipse itself. We now know that the phenomena in all

their strangeness are due to the fact that for hundreds of thousands of miles outside the sun that we ordinarily see, a kind of atmosphere exists, so little luminous in comparison to the sun that we know, that it remains invisible except when the dark body of the moon shields us from the light of the central portion It is this relatively feebly luminous atmosphere that we see apparently surrounding the dark moon.

But it may be asked, why do eclipses happen so rarely, since the moon goes round the earth and therefore should come between the sun and earth every month? The answer is, that the planes of the two movements do not coincide. When the moon is new, that is, between us and the sun, if we could see her she would sometimes be *above*, at others *below* the line joining earth and sun.

If this were not so, every new moon *would* put out the sun; and further, as the earth and every body through which light cannot pass, both on the earth and off it, cast a shadow, every full moon would be hidden in that shadow. Thus there would be an eclipse of the moon as well as of the sun every month, that being the period of time which the moon requires to accomplish one complete revolution in her orbit round the earth in relation to the sun.

To go for one moment into detail; since the plane of the moon's movement round the earth does not coincide with the plane of the earth's movement round the sun, as we have seen; one-half of the moon's journey must be performed above and one-half below the plane of the earth's movement round the sun; the two points where the planes cross are called the *nodes*, and it is only when the moon is in or near these that eclipses can occur.

If the moon at these times happens to be new or full, that is, in line with the earth and sun, we shall have in one case an eclipse of the sun, and in the other an eclipse of the moon. The accompanying figure will help to make this more clear:—

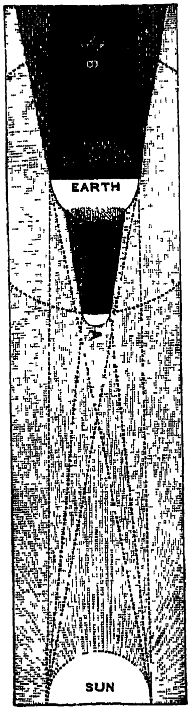

FIG. 1.—Eclipses of the sun and moon.

We have the sun at the bottom, the earth at the top, and the moon in tw positions marked *A* and *B*, the level of the page representing the level, c plane, of the ecliptic. We suppose therefore that the moon is at a node —tha is, on that level, neither above nor below it.

At *A*, therefore, the moon stops the sun's light, its shadow falls on a part c the earth; and the people, therefore, who live on that particular part of where the shadow falls cannot see the sun, because the moon is in the wa Hence we shall have what is called an *eclipse of the sun.*

At *B* the moon is in the shadow of the earth cast by the sun; therefore tl moon cannot receive any light from the sun, because the earth is in the wa Hence we shall have what is called an *eclipse of the moon.*

Although solar eclipses, generally speaking, occur ve frequently, a *total* eclipse of the sun happens only occasionall This arises from the circumstances that the distances betwe earth and sun and earth and moon are constantly changing, a

hence their relative apparent sizes change. When the sun is nearer and the moon further off than usual, the apparent size of the moon is smaller than that of the sun, and the eclipse is *annular* instead of *total*; under these circumstances her shadow is not long enough to extend to the earth's surface. In such cases as these the sun is not totally covered over or eclipsed by the disc of the moon, but at the time of mid-eclipse displays a ring. *Partial* eclipses occur when the moon, not exactly at the node, does not entirely cover the disc of the sun, but passes above or below the centre.

It will be easily seen from the figure, that whereas an eclipse of the moon by the shadow of the much larger earth will be visible to the whole side of the earth turned away from the sun, the shadow cast by the small moon in a solar eclipse is, on the contrary, so limited, that the eclipse is only seen along a narrow strip of the earth's surface, the width of which averages about 150 miles, and it sweeps across the surface of the earth from west to east with great rapidity in consequence of the comparatively great speed of the moon in its orbit round the earth, and the movement of the earth on its axis.

Not only can the eclipse be seen only from a very thin line stretching over the earth's surface, but the time of duration is also very short. The longest time an eclipse of the sun can be total at any place is seven minutes. As a rule, however, we do not have the conditions for giving us the longest amount of time for totality, so that we have to put up with a much smaller time of observation.

This much having been premised, we may now pass to the strange appearances seen at such times. These, in fact, constitute the chief points to which attention should be directed. When the disc of the moon has advanced so far over that of the sun that the latter is a very thin crescent—that is, immediately before the beginning of totality—the crescent appears suddenly as an irregular band of brilliant points, sometimes separated by

dark spaces so as to give it the appearance of a string of beads, which appear to move and merge into one another.

When this happens, and sometimes even before it happens, the moon beyond the cusps, that is the ends of the thin crescent, may be seen projected on something dimly visible surrounding the sun.

At the moment of the beginning of totality, about which there is no mistake, for the shadow of the moon comes like a solid mass sweeping through the air and along the landscape, this observation is explained. The solar surroundings, invisible at all other times, burst forth round the black moon. I first saw this in 1871, and this is what I wrote at the time:—

". . . There in the leaden-coloured, utterly cloudless sky, shone out the eclipsed sun! a worthy sight for gods and men. There, rigid in the

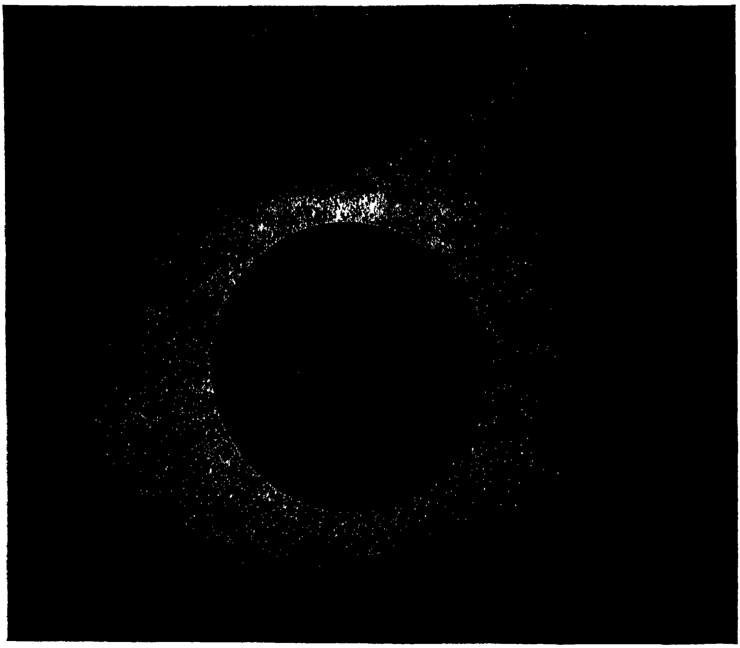

FIG. 2.—The Solar Corona.

heavens, was what struck everybody as a decoration, one that Emperors might fight for; a thousand times more brilliant even than the Star of India, where we then were! a picture of surpassing loveliness, and giving one the idea of serenity among all the activity that was going on below; shining with a sheen as of silver essence; built up of rays almost symmetrically arranged round a bright ring above and below, with a marked absence of them right and left, the rays being composed of sharp radial lines, separated by furrows of markedly less brilliancy."

Let us first examine the details near the moon, a region vastly brighter than that further away, glowing with variously coloured light but chiefly red, the masses of colour having a very irregular outline, and all joined into a continuous envelope at the bottom. Here we have the "red flames" and "red protuberances" of the text-books, in fact the solar chromosphere and prominences. These are always seen round the margin of the moon's edge immediately after the commencement of totality; they have been noticed with certainty since the year 1706, when Captain Stannyan wrote of the eclipsed sun that "his getting out of his eclipse was preceded by a blood-red streak of light from his left limb, which continued not longer than six or seven seconds of time . . . " and they have been photographed since 1860.

Such then is a general idea of the world of marvels revealed the moment the strong sunlight is shut off from our upper air, producing a darkness which enables us to observe not only these new regions but the stars as well.

It can be well imagined that many questions depend for their solution upon the inquiries which are only possible during an eclipse; suffice to say that there is a great number of them; spectroscopes and cameras have, therefore, to be diligently employed in the hands of skilled astronomers and photographers at such times.

The official parties representing the different nations and observatories have, of course, to be at the place of observation for some time previous to the eclipse, as there is much preparation needful. The country has first to be explored for the best

sites; a clear view of that part of the sky where the eclipse takes place, and the local cloud drifts being among the first things to be considered. Then comes the erection of the observatories, in some sheltered spot if high winds are probable, and the setting up and careful adjustment of instruments. For these latter, observation of stars are necessary, and hence a good margin of time is requisite. When all these things have been looked to, careful drills at the exact time of the eclipse are essential, and the more of these the better. A month's interval is not too long for these preparations; a fortnight should be considered as an irreducible minimum, for delays may occur even on the voyage to the place of observation.

CHAPTER II.—ECLIPSE WORK FOR AMATEURS.

TIME OBSERVATIONS.

OBSERVERS who are supplied with a first-rate chronometer, of which the error and rate are known, may make valuable observations of the four contacts.

For the first contact a telescope is necessary to observe the first small encroachment of the moon on the sun's limb; of course, if a spectroscope be used to observe the gradual eclipse of the chromosphere indicated by the gradual shortening of one of the lines of hydrogen (C for choice), so much the better; but care must be taken by sweeping along the limb to secure that the chromosphere immediately above the first contact is under observation; here, of course, the line will be shortest.

The second contact will be heralded by the sweep of the moon's shadow through the air. Mr. Crommelin has calculated that in 1896 this moved at the rate of 2 miles a second; the shadow on the land- or sea-scape will, of course, be best seen from the most elevated stations.

To observe the exact time of contact, a green shade should be used, as the disappearance of the white light of the photosphere and the appearance of the red light of the chromosphere will be emphasised. Professor Harkness has also pointed out that the exact moment of second contact is also clearly indicated by the "seemingly miraculous appearance of the complete outline of the moon, round and black, reposing upon the wondrous radiance of the corona."

The approach of the third contact is indicated by the rapid brightening of the chromosphere at the point of the moon's limb where the sun is about to reappear. The green shade should again be used, and two or three seconds later a fine cusp of photosphere will make its appearance, announcing the termination of totality.

The green shade is here especially useful, as often the reappearance of the lower brighter chromospheric level has been mistaken for the reappearance of the sun itself.

For the fourth contact a telescope should be used if possible, otherwise a smoked glass.

Disc Observations.

These observations are for noting the greatest extent of the corona, and can only be made by shore parties.

Calculate the altitude and azimuth of sun's centre, at place, at mid-eclipse. Make a disc of such a size that at a distance *from the eye* of 20, 30, or 40 feet, as may be decided on, it will cover the sun, and extend three minutes of arc beyond the limb all round. Erect this on a pole, so that from the observing point chosen it will eclipse the dark moon and the lower parts of the corona (3′ high) at mid-eclipse.[1]

A hole should be cut in a piece of wood or cardboard, fixed at the proper height, to show the exact position of the eye. This should be free to move in altitude and azimuth to secure exact adjustment.

Test the accuracy of everything, if possible, the day before at the time the sun is nearest the mid-eclipse position.

Before totality one observer should make the adjustments before referred to, and should see that at ten seconds after the beginning of totality the lower part of the corona all round the dark moon is completely covered by the disc.

Another observer, whose eye has been lightly bandaged to

[1] See *post*, pages 22, 77, and 96.

make it as sensitive to faint light as possible, should then be placed at the eye-hole, and should look for the faintest extensions. He should dictate to an amanuensis the length of extensions in diameters of dark moon; and their bearing, the vertex representing magnetic north.

Immediately the totality is over, the actual observer should draw what he has seen on a card similar to that used by the sketchers of the corona (see later). This drawing should include everything seen, but the extensions should be noted with the greatest care.

It is desirable that, if possible, each party observing the contacts should consist of three persons; one to watch, without any interruption whatever, the face of the chronometer and to count the seconds immediately before each contact is expected, another to make the observation, and the third to record the exact time, minute, second, and part of second at which the signal is given by the second observer.

Eye Observations of the Corona.

All can do serviceable work by sketching very carefully the corona during the time of totality. The observers should provide themselves with a card (or cards) one foot square, on which a circle 2 inches in diameter is drawn in ink, and darkened to represent the moon's disc. The diameter will serve as a scale, so that the distance the boundaries and rays of the corona extend from the dark moon may be carefully noted. Imagine both the dark moon and dark disc to represent a compass card, then the various details may be sketched at their appropriate bearings, the top of the card representing mag. N. (The points may be marked on the card in any detail that may be required, but eight should suffice.)

These observations should, if possible, be made by observers in pairs, and they should not compare notes. If telescopes are

used, 2 inches aperture and a power of twenty should be employed for choice.

Before Totality.

The sketchers are advised, previous to totality, to shield their eyes to a certain extent from the direct rays of the sun, otherwise the more delicate details of the corona will not be seen under the best conditions.

(I) Note how long before totality the corona is visible along the edge of the dark moon opposite the point at which the sun is about to disappear.

(II) Sketch any rays visible before totality; give length, colour, and structure as well as position.

At Commencement of Totality.

There need be no fear that the instant of the commencement of totality will be missed. The rapid and often terror-inspiring sweep of the moon's shadow through the air generally marks it beyond all question. If the observer occupies an elevated situation, the shadow will be seen sweeping over the distant landscape some seconds before totality.

(III) Sketch general outline and rays (streamers) and rifts (dark intervals between bright rays).

(IV) Note if there be a blaze of light or glare where the sun has just disappeared, and whether the base of the corona is brightest near or away from prominences.

Middle of Totality.

(V) Sketch general outline, rays (streamers) and rifts; note colour and direction of greatest extension.

Near End of Totality.

(VI) Sketch general outline, and any rays or streamers or rifts; note colours.

(VII) Note if there be a blaze of light or glare where the sun is about to reappear.

After Totality.

(VIII) Sketch any rays that may be visible; give length, colour, and structure, as well as position.

Questions to be Answered in Writing immediately Totality is Over.

(*a*) Has there been any change in the appearance of the corona during the eclipse? If so, specify what change.

(*b*) Have, especially, the dark rays or rifts changed during the eclipse?

(*c*) Describe what has been unchanged throughout, and define its structure.

(*d*) State the colours you observed outside the red prominences.

(*e*) Were the colours anywhere arranged in layers round the sun?

(*f*) Were the colours anywhere arranged radially?

(*g*) State colours of rays, and of spaces between them.

(*h*) Did the dark rifts extend down to the moon, or did they stop short above the denser layers of the chromosphere?

(*i*) Were the rays brightest near or far away from the moon?

(*k*) What was the comparative brightness of the rays, the bright ring near the sun, and the outer corona?

Colours of Land- and Sea-scape.

Some time before totality there will be a notable change in the colours of sky, cloud, and land and water surfaces.

Each of these should be noted separately, and the gradual

changes, both as totality is approached and after it is over, should be carefully recorded.

Halley, in his account of the total eclipse of 1715, wrote:—

> "When the eclipse was about 10 digits (that is when about five-sixths of the solar diameter was immersed), the face and colour of the sky began to change from perfect serene azure blue to a more dusky livid colour, intermixed with a tinge of purple, and grew darker and darker till the total immersion of the sun."

This apparent change of colour has its origin in the coloured chromosphere and prominences; those witnessing the eclipse are thus enveloped in coloured—generally red—light, which bathes the landscape. The sky, ordinarily blue, is seen through a red haze, and therefore puts on a purple tint

That the sky appears more purple at some eclipses than at others, is owing to the fact that the quantity of red light is not always the same, but varies with the brightness and magnitude of the prominences visible at the time.

This notable change in the colours of sky, cloud, and land and water surfaces will be seen some time before totality.

Each of these should be noted separately, and the gradual changes, both as totality is approached and after it is over, should be carefully recorded.

The following table will give an idea of the colours, both of the corona and landscape, which have been previously remarked.

Table of Colours.

Year	Inner corona	Outer corona	Rays	Landscape, &c.
1605	Reddish hue (Kepler)			
1715	Pale whiteness or rather pearl coloured (Halley)			
1733	Ruddy (Vatterini)	Greenish colour		
1766	Ruddy	Yellow and white		Livid yellow (Le Gentil).

Table of Colours—continued.

Year.	Inner corona	Outer corona.	Rays.	Landscape, &c
1778	Reddish hue, pale yellow to white (Ulloa)			
1806			Bluish tint (de Witt)	
1842	Yellow			
1842	Peach colour (Airy)			Greenish olive (Pinaud)
				Greyish violet heavens at Lipesk
1851	White first and then blue			Land dusky yellow, water deep purple, clouds yellow, sky purple (Dunkin).
	Dull rose colour			
	Light violet			
				Sea and land dark green. Deep yellow colour beneath clouds in south (Snow)
	Pure white Brightest (Carrington)	More feeble (Carrington)		Landscape dark olive tint (Hind).
	Silvery white (Swan)			
				Clouds deep purplish grey (Dawes).
	Light violet, nearly white (Silverstolpe)			A sickly neutral green coloured sea and tinged atmosphere.
	A cold unearthly light (Adams)			
	Orange (Liveing)			
1860	Yellow (Rumker)			
1869	Silvery grey (Farrell)		Fine violet mauve coloured white and yellowish white (Farrell)	
	Silvery white. Greenish violet (Eastman)			
	Clear yellowish	Pinkish green (Myer)	Silvery	Bands of pink, purple, yellow, orange, fiery red, no green or blue except a blue tinge in purple, all divided by black stripes

THE VISIBILITY OF STARS DURING AN ECLIPSE.

The light radiated by the solar surroundings varies very much from eclipse to eclipse. Hence sometimes lamps are necessary for certain of the operations, while at others they are superfluous.

The number of stars visible, therefore, varies considerably.

Note, by means of a star map, what is the magnitude of the faintest stars visible, whether first, second, third, or fourth.

SUGGESTIONS FOR TIMING THE PROGRESS OF THE ECLIPSE.

In Sicily, in 1870, the following method of recording the lapse of time during totality was introduced, and was found to prevent all excitement, and made the eighty seconds seem a long time.

Determine the number of seconds of totality at the station—say 100.

Then, at the moment of totality, let a person attached to each party of observers, carefully observing the face of a chronometer or watch, say, "You have now 100 seconds." After five seconds, "You have still ninety-five seconds." After another five seconds, "There are still ninety seconds remaining." And so on.

USE OF SMALL CAMERAS.

Those who possess moderate sized cameras can do useful work by employing their time during totality in making a few short exposures on the corona.

The instruments should of course be most carefully focussed for very distant objects, and it is advisable to employ a small finder properly adjusted, so that the object to be photographed should be in the centre of the field of both camera and finder simultaneously. The times of exposure of course will depend on the sensitiveness of the plates used.

Use of Small Telescopes.

Observers equipped with telescopes, whether they be small instruments or equatorially mounted, must be very careful about not observing the sun before or after totality without the aid of dark glasses. For small hand-telescopes a dark glass will be found sufficiently safe, but with instruments of greater power, the dark glass should be supplemented by a solar or diagonal eye-piece; if one-half of the reflecting surface of the glass be silvered and the glass be made to slide, it may be used during totality. In any case *don't forget, before totality, to remove the dark glasses.*

With such instruments, the chief work of the observers should be, during totality, the study of the forms, colour, and details of the prominences, and any striking phenomenon that at the moment might meet the eye, such as the details of the corona and the colour of the corona itself.

A Small Prismatic Camera.

A small prism placed in front of even a pocket telescope will give a very good idea of one of the most important pieces of work undertaken by the official astronomers, but in this case, if the angle of the prism be, say, 10°, then the telescope must be directed 10° above or below the sun if the edges of the prism are horizontal. It is desirable, therefore, that the instrument be supplied with a finder of some rough kind inclined to it at the appropriate angle.

What will be seen in an instrument of this kind is a series of images of the sun's surroundings composed of rings glowing with different coloured light from blue to red; each coloured ring or tiniest speck of colour having its story to tell of the chemical substances present. But this is a long story!

The would-be observers should, some days before the eclipse, make up their minds where they will observe. This should be

as far from the haunts of man as possible, and the observers should scatter widely. The natives will crowd the observers, and their talk, and perhaps even their fears, may much interfere with observations.

In India, in 1871, my observations would certainly have been rendered impossible by the smoke of sacrificial fires to frighten away Rahu, the Dragon which is supposed to cause eclipses by swallowing the sun, if there had not been a strong force of military and police present to extinguish them; and in Egypt, in 1882, without the protection of the soldiers, a crowd of Egyptians would have invaded the camp; as it was, their shouts and shrieks from a distance of some 500 yards were plainly audible.

CHAPTER III.—THE ECLIPSE PROBLEM IN 1896.

It forms no part of my present purpose to give a history of the various eclipses that have been observed, say, since 1870, the first year in which I took part in eclipse observations, or to set out the work attempted or accomplished in each. Still, in considering the recent eclipse, it will be useful to begin by stating the problems which were awaiting solution in 1896, and in doing this some of the prior eclipse work must of necessity be passed under review.

Before I begin, therefore, to give an account of what I attempted to do in 1896, it will be well to state what, in my opinion at all events, was the most important work to be done in the then state of our knowledge.

In looking back among the published eclipse records, it is not a little surprising to note how the attack has varied in the importance attributed to certain of the inquiries, and how often it has happened that the chief scientific result secured at any eclipse was hardly dreamt of by the organisers of the expeditions. But when there has been this notable divergence between anticipation and actual achievement, the work done has proved of the greatest advantage to science. I should not have been sorry, therefore, if the following anticipations had failed to include the most important advances made during the eclipse of 1896.

In the first place, the records obtained in 1893 by large scale prismatic cameras showed everybody that these instru-

ments were the most important ones we can employ on an eclipsed sun. They not only give us a complete chemical record, on a scale hitherto undreamt of, but they give us the positions and forms of the prominences far better than these have ever been obtained before. Nor is this all, they enable us to study under new conditions some of the conclusions arrived at in previous eclipses, and give us a means of inquiring into the possible origin of some of the phenomena already recorded by slit spectroscopes.

It is now more than a quarter of a century since bright lines were recorded during a solar eclipse in the spectrum of the dark moon. There could, of course, never have been any doubt that this was due to chromospheric glare reflected by our atmosphere; but the moment this was conceded, the more difficult it became to determine the exact height of the solar envelopes, for if there were glare over the dark moon, how high might it not extend over the prominences?

Now one of the important points about the prismatic camera is that it is quite impossible for it to treat such a general glare as this in the same way as it does any local illumination; as a result of this property any effect due to general glare which *can* be recorded by a slit spectroscope *cannot* practically be recorded by the prismatic camera; and so, roughly speaking, a comparison of the two records may be safely trusted to eliminate the effects of such glare.

It will be generally recognised that this is an important service to render; but there is another which, from the chemical point of view, is more important still—it enables us to localise the origin of the various radiations which build up the spectrum of the sun's surroundings, whether it be high or low.

For the first time in 1893 the corona was photographed as a ring by means of the prismatic camera, and apparently associated with this were other rings in the ultra-violet. The

coronal ring in the green was best shown in the Brazilian photographs taken by Mr. Shackleton, but the others in the series taken by Mr. Fowler in West Africa. Now we find that the brightness of these coronal rings seems to depend upon proximity to the equator, and is entirely independent of the prominences. That the true spectrum of the corona will be eventually thus determined is unquestioned, and the sooner it is done the better. This part of the attack in 1896 was greatly strengthened, and not only had we in Lapland prismatic cameras of 6 and 9 inches aperture, but I equipped Mr. Shackleton with a powerful instrument for his observations in Novaya Zemlya, whither he went in the expedition rendered possible by the public spirit of Sir George Baden-Powell.

The large scale prismatic camera was, as I have said, introduced in 1893—that is, only four years ago. The results obtained in that year represent, therefore, only the experimental stage; at the critical moments of the eclipse—that is, at the beginning and end of totality—only snap-shots were taken. In 1896 what is termed a dropping-plate was introduced in the programme of the prismatic camera, a plate being exposed, while gradually falling, from ten seconds before the end of totality to fifteen seconds after, in the hopes of catching the so-called "flash" which is supposed to represent the "reversing layer," which "flash" of course is simply the spectrum of the chromosphere.

So much then, briefly, for the prismatic cameras and the pre-eminent importance of their use. I next come to another point, to investigate which a powerful instrument was allocated in 1896.

In organising the work for the eclipse of 1871, stress was laid on the importance of obtaining a photograph of *all* the light radiated earthwards during an eclipse, to supplement the work of the slit spectroscopes which had to do with the light radiated by *special parts* of the solar surroundings.

This work is a thousand times more important now that the spectrum of the prominences is so clearly separated from that of the corona by the prismatic cameras, because it enables us to make a flank attack, so to speak, on the corona spectrum.

The integrating spectroscope prepared for use in 1896 consisted of a 4-inch Taylor lens of long focus as collimator directed to the sun's place during totality in a way I will state further on; then come two prisms of 60° of dense flint, and, lastly, a camera of 19 inches focus. It was found that light reflected from a dark cloud gave an exquisitely sharp and well-dispersed solar spectrum in 40 seconds.

Now in this instrument, simply pointed to the sun's place, *the light from the greatest area will give the brightest lines.* We might therefore expect the coronal lines to be well visible ; and when prismatic cameras secure a complete record of the chromosphere and prominence spectrum, a simple subtraction will bring us face to face with the spectrum of the upper reaches of the solar atmosphere.

I next come to another matter on which I determined to lay great stress in 1896. It is well known that Professor Newcomb, in 1878, introduced into eclipse work the use of a disc, behind which the brighter lower layers of the sun's atmosphere, apparently surrounding the dark moon, were hidden during the totality. The object of this is, of course, to shield the eye, and an additional precaution is to blindfold the observer till totality has well commenced.

Armed in this way, Professor Newcomb was enabled to see long luminous extensions, equalling in length several diameters of the dark moon, along the sun's equator. Now, since such long streamers had never been seen before, it has been imagined that they indicate a special form of corona visible at the period of minimum sun-spot activity, for it was at very nearly this period that the eclipse of 1878 occurred.

But it may well be that the appearance may be due to the method employed, and that such an equatorial extension may be always there if only we can see it, and the greater the solar activity the more difficult is it to see it ordinarily, because this greater activity is always accompanied by a brighter lower corona.

Professor Newcomb, I believe, used a disc of such a size that the brighter lower corona some 3 minutes of arc above the dark moon was covered. I proposed to repeat this observation, and to extend it by using several discs, one or more of which will cut off 5 minutes of arc.

Finally, I have a few words to say on the various features of the corona independently of the large extension which can best be specially dealt with by the disc observers.

The enormous difference between the shape and brilliancy of the corona at the periods of maximum and minimum sun-spot activity was one of the revelations—the *unanticipated* revelations—of the eclipse of 1878. In that year the appearances of the corona in 1871, a year of sun-spot maximum, were fresh in my mind, and, fortunately, the eclipse of 1878 occurred at the period of minimum. The difference was marked in every way, and I said so. For a time the statement was disputed, nay, ridiculed, but I think everybody accepts it now. The conclusion was further intensified during the eclipse of 1886, which also took place near a minimum. In that year the eclipse happened in the morning, the observation place was Green Island in the West Indies, in the middle of the rainy season, and the only thing I saw was first a cloud, which formed and began to obscure the sun soon after the first contact, and grew till after totality; and next, some patches of sky away from the cloud-eclipsed eclipse. These patches swarmed with stars as on a darkish night; full moonlight was never suggested.

During the eclipse of 1896, the sun occupied a position in the

constellation Leo, such that, besides planets, many stars of the first, second, third, and fourth magnitudes were conveniently situated for observation. It was obvious, then, that we had here, if it could be properly utilised, a method of photometry easily applied, and I proposed, if possible, to utilise it, since where doubt exists the more methods of observation we employ the better.

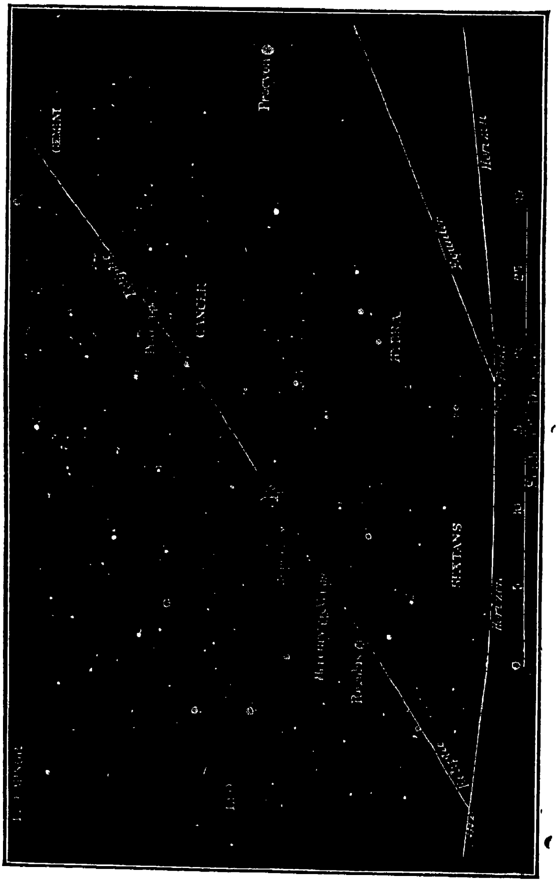

FIG. 3.—Stars and planets near the sun at the time of totality during the eclipse of 1896.

Such, then, were some of the points to which I attached the greatest weight in 1896.

So much has been said of the importance of the use of the prismatic camera that I shall devote the next chapter to that instrument. Other points referred to will be dealt with in more detail in subsequent chapters.

CHAPTER IV.—THE PRISMATIC CAMERA.

FRAUNHOFER, at the beginning of the century, found that in order to observe the spectra of stars the best thing to do was to put a prism outside a telescope, and to let the light enter the telescope and be brought to a focus after it had passed through the prism; and it is a most unfortunate thing, that the neglect of the application of this principle has landed us probably in a delay of fifteen or twenty years in gathering knowledge on this subject. Now the spectroscopes with which we are most familiar are armed with a slit through which the light to be examined is made to enter, and the rays are next rendered parallel before they enter the prism in a part of the instrument called the collimator. After passing the prism they are again collected to a focus by means of a telescope.

But a spectroscope need not be so complicated as this, for after all the object of the instrument is to disperse white light as we see it dispersed in a rainbow, and what nature accomplishes by a rain-drop we can do by a prism; hence, if we simply pass a ray of white light through a prism, we find that after it has so passed through, it is changed into a beautiful band, showing all the colours of the rainbow. This prism then is the fundamental part of the instrument, and the most complicated spectroscope which we can imagine simply utilises the part which the prism plays in breaking up a beam of white light into its constituent parts from the red to the violet. Between these colours we get that string of orange, yellow,

green and blue, with which we are familiar in the rainbow. For sixpence any of us may make for ourselves an instrument which will serve the purpose of demonstrating many important spectroscopic results. From an optician we can get a small glass prism for sixpence; glue it at one end of a piece of wood about 12 × 1 × ½ inch, so that we can see through it a coloured image of a needle stuck in at the other end of the

FIG. 4.—A simple form of spectroscope.

piece of wood (Fig. 4). This we must do by looking sideways through it.

Allow the needle to be illuminated by the flame of a spirit lamp into which salt is gradually allowed to fall. We see an image of the needle coloured in orange. If we next illuminate the needle by a candle or gas flame, taking care that the direct light from the candle does not fall upon the face of the prism, we then get no longer a single image of the needle, but a complete band of colour from red to blue. We have, in fact, an innumerable multitude of images of the needle close together.

It will be clear from these experiments that in our *impromptu* spectroscope we see simply images of the needle, few or many, according as the kind of light we are studying contains few or many differently coloured rays.

In the more complicated instrument we pass from an illuminated needle to a fine straight slit through which light is allowed to enter. We generally talk of "line" spectra for the reason that a narrow slit is employed, the image of which is a line. In the "lines" seen in the spectra of the heavenly bodies we have so many celestial hieroglyphics which we have to translate into chemical language by comparing their positions with those we observe in the spectra of terrestrial light sources.

These positions are now defined by the "wave-length" of the "line" under examination expressed in ten millionths of a millimetre; these wave-lengths increase from the violet to the red. Formerly empirical scales were used, such as that of Kirchhoff. "1474 K" is thus a "short title" of the corona line which occupied this position on his scale. Fraunhofer lettered the principal dark lines in the solar spectrum "A," "B," &c., beginning with the red; H and K are the last visible lettered lines in the violet.

But a straight slit is not the only kind of aperture we can employ; we may replace it by a ring, for instance.

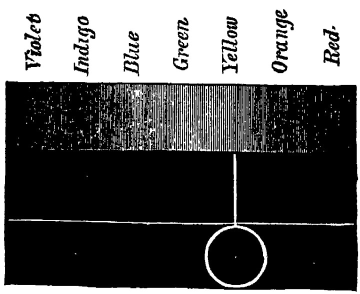

FIG. 5.—The spectra of continuous and discontinuous light sources, the latter seen with a line and circular slit.

What we shall see in passing from the spectrum of a candle to the spectrum of a spirit-lamp flame with salt in it, using first a straight and then a circular slit, is shown in the accompanying woodcut (Fig. 5).

If we examine a very complicated light-source we shall arrive at the same result, a spectrum characterised by a large number of bright circles or lines (Fig. 6).

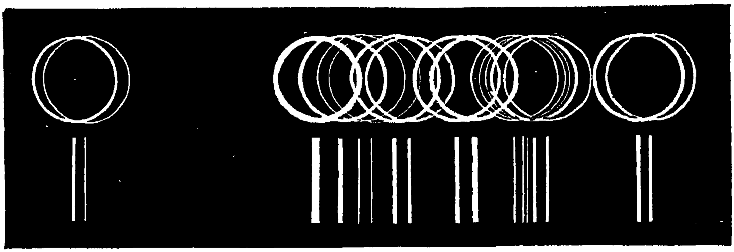

FIG. 6.—The spectrum of a complicated light-source as seen with a circular and a line slit.

We have seen that in an ordinary spectroscope, when we are studying light-sources close to us, the rays have to be made parallel before they pass through the prism. But the heavenly bodies are at such a distance from us that their light reaches us in a parallel beam, so that one part of the spectroscope, the collimator, may be dispensed with. A star as a point is part of a line slit; hence the success of Fraunhofer's arrangement for observing stellar spectra, to which I have referred. In an eclipse we get a bright narrow ring round the dark moon. There is our ring slit. Hence the so-called "slitless spectroscope," or prismatic camera," as it is called when photography is employed, used to study the spectra of stars and the sun's chromosphere during eclipses.

The way in which, in the prismatic camera, the prism is fixed outside the object-glass, is shown in the accompanying figure (Fig. 7).

FIG 7.—Details of objective prism.

To follow the sun during the eclipse the telescope with its prism outside the object glass must be equatorially mounted. But another thing is necessary to be considered besides this. The prism should lie on the object glass in such a way that its direction of dispersion will give us the best results at the second and third contacts, that is at the beginning and end of totality. The annexed woodcut, giving the contact conditions for the eclipse of 1893, indicates that it is generally necessary to effect

a compromise by taking the prism with its refracting edge along or at right angles to a parallel of declination.

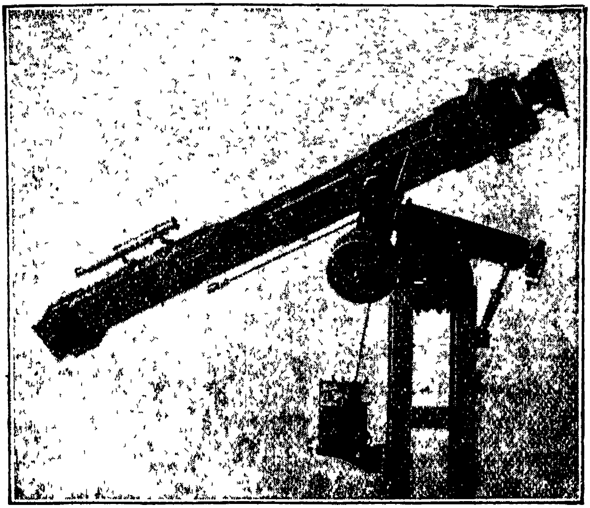

FIG. 8.—A prismatic camera mounted equatorially.

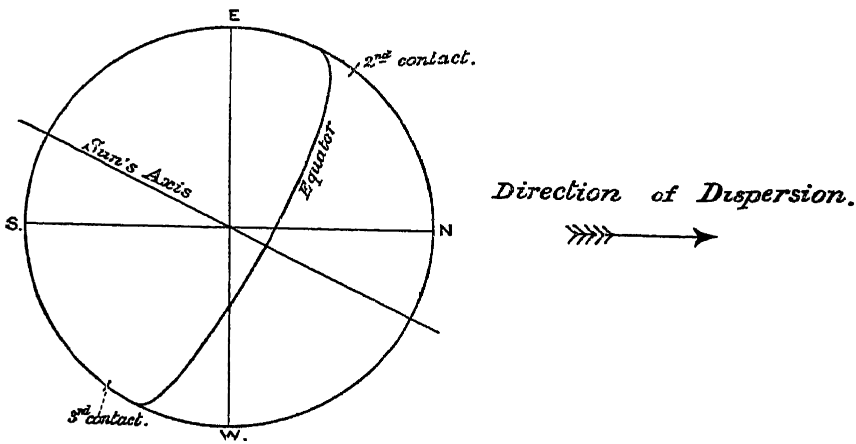

FIG. 9.—The contact conditions and direction of dispersion employed in 1893.

We are now in a position to inquire how this arrangement has been used during eclipses since 1871.

CHAPTER V.—THE USE OF THE PRISMATIC CAMERA IN PRIOR ECLIPSES.

The Eclipses of 1871—1886.

The considerations which led me, in 1871, to employ a spectroscope without collimator may here again be summarised. If in an ordinary spectroscope, the straight slit be replaced by a circular one, bright rings replace the bright lines which are ordinarily seen in radiation spectra; and since in the solar surroundings we have chiefly to deal with radiation phenomena, the chromosphere and corona themselves can be used during an eclipse as ring slits, and on account of their distance, a collimating lens can be dispensed with.

In the report on the eclipse of 1875, by Dr. Schuster and myself, the principles of the method, as applicable to photographs taken during totality, were stated as follows.[1]

"Supposing that the corona and chromosphere only send out the same homogeneous light, one image only will appear on the sensitive plate, the only effect of the prism being to displace the image. As far as the protuberances are concerned we know they give a spectrum of bright lines, and we expect, therefore, to find on the plate each protuberance represented as many times as it contains lines in the photographic region. The different protuberances would be arranged in a circle round the sun, and these circles would overlap or not, according to the dispersive power of the prism and the difference in refrangibility of the lines. . . . If the corona gives a series of bright lines we shall find a series of outlines on the photographs similar to that corresponding to the protuberances. . . . If we find that part of the corona gives a continuous spectrum, that part alone will be drawn out into a band."

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[1] *Phil. Trans.*, 1878, Part I, p. 139.

To this it may be added, that successive photographs will differ on account of the difference of phase. One part of the chromosphere will be visible at the beginning of totality, and another part at the end. The smaller prominences visible at the beginning of totality are subsequently eclipsed by the moon, and their spectra are consequently absent from later photographs, while a new prominence region makes its appearance. In the same way, the part of the corona of which the spectrum is photographed will vary at different phases, but only in the lower parts.

The results obtained by Professor Respighi and myself during the eclipse of 1871 in India, in which part of the attack consisted in the employment of slitless spectroscopes—a method of work at which we had arrived independently—indicated the extreme value of such observations.

For my own observations in 1871 I had arranged a train of five prisms without either collimator or observing telescope.

"I saw four rings with projections defining the prominences. In brightness, C came first, then F, then G, and last of all 1474 K. Further, the rings were nearly all the same thickness, certainly not more than 2′ high, and they were all enveloped in a band of continuous spectrum."[1]

Respighi's observations were made with a telescope of 4½ inches aperture, with a large prism of small angle in front of the object-glass. The principal results obtained by him were as follows:—[2]

"At the very instant of totality, the field of the telescope exhibited a most astonishing spectacle. The chromosphere at the edge, which was the last to be eclipsed, . . . was reproduced in the four spectral lines, C, D_3, F, and G, with extraordinary intensity of light. . . .

"Meanwhile the coloured zones of the corona became continually more strongly marked, one in the red corresponding with the line C, another in the green, probably coinciding with the line 1474 of Kirchhoff's scale, and a third in the blue, perhaps coinciding with F."

"The green zone surrounding the disc of the moon was the brightest, the most uniform, and the best defined."

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[1] *Nature*, vol v, p. 218, 1872.

[2] *Ibid*, p. 237, 1872.

My observation[1] was made immediately between the two observations of Professor Respighi. The observations may be thus compared:—

Respighi	C	D_3 ...	F.G.	Chromosphere and prominences at beginning of totality.
Lockyer	C	1474 (faint)	F.G.	Corona 80 secs. after beginning of totality.
Respighi	C	1474 (strong)	F.	Later.

I had no object-glass to collect light, but I had more prisms to disperse it, so that with me the rings were not so high as those observed by Respighi, because I had not so much light to work with; but such as they were, I saw them better, because the continuous spectrum was more dispersed, and the rings (the images of the corona), therefore, did not overlap. Hence, doubtless, Respighi missed the violet ring which I saw; but both that and 1474 were very dim, while C shone out with marvellous brilliancy, and D_3 was absent.

In arranging for the eclipse of 1875 in Siam and the Nicobars, the method was further developed by the introduction of photography, and the first results of this extension were given in the Report of the Eclipse Expedition of that year. They showed clearly that with the rapid dry plates of to-day a considerable increase of dispersion might be attempted.

The object-glass employed on this occasion had an aperture of 3¾ inches and a focal length of 5 feet, while the prism had a refracting angle of 8°.

Two photographs were obtained with exposures of one and two minutes respectively. Both are reproduced in the Report,[2] and they show only such differences as can be attributed to difference of phase. The dispersion was very small compared with the size of the sun's image, so that the photographs present the appearance of an ordinary photograph of the eclipsed

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[1] *Brit. Assoc. Report*, 1872, p. 331.

[2] *Phil. Trans.*, 1878, vol. clxix, Part I, p 139.

sun, which is slightly distended in the direction of dispersion. The various prominences each show three images, two of which were identified with H_β, H_γ, while the others were found to correspond to a wave-length of about 3957.

It was suggested[1] that this represented the H and K radiations of calcium, and this is fully confirmed by the results obtained in 1893, to say nothing of results obtained in other eclipses.

I next proceed to remark very briefly upon the photographic results obtained since 1875. In 1878, near the sun-spot minimum, the method was employed by several observers, myself among them, but no *bright* rings were recorded. The maximum sun-spot conditions previously observed had entirely changed; indeed with a slit spectroscope the 1474 line was very feeble, and was only seen by a few of the observers, and hydrogen lines were similarly feeble.[2]

Part of my own equipment for this eclipse consisted of a small grating placed in front of an ordinary portrait camera, and with this I obtained a photograph showing only a very distinct continuous spectrum.[3]

The method was employed by Dr. Schuster in Egypt in 1882; the camera was of 3 inches aperture and 20 inches focal length, with a prism having a refracting angle of 60°.[4] The single photograph obtained (not reproduced in the Report) was stated to show two rings, which were considered to be due to the lower parts of the corona, and therefore to correspond to true coronal light. The wave-length of one of these rings was measured to be 5315; it is due to the green corona line (1474K). The second was stated to be coincident with D_3.

[1] *Report*, p. 149.

[2] *American Journal of Science*, vol. xvi, p. 243.

[3] With a duplicate grating I observed the spectrum of the eclipsed sun, and again in three different orders saw nothing but continuous spectrum (*Nature*, vol. xviii, 1878, p. 459).

[4] *Phil. Trans.*, vol. clxxv, 1884, p. 262.

In 1883 the instrument used in Egypt in 1882 was again employed, as well as a 6-inch achromatic telescope, and a concave Rowland grating of 5 feet focus, arranged for taking ring spectra in the first and second orders.

It is stated in the Report[1] that the photographs "possess no features of interest," and neither reproductions nor drawings nor measurements are given.

The prismatic camera employed in the eclipses of 1882 and 1883 was again used in the West Indies in 1886. Only the spectra of some prominences seem to have been recorded. There is no mention of rings. The hydrogen lines as well as K and *f* are noted.[2]

While on the one hand the photographic results, to which reference has been made, certainly did not come up to the expectations raised by my observations of 1871, on the other, subsequent solar investigations confirmed my opinion that this was the best way of studying the lower parts of the sun's atmosphere, provided an instrument of much greater light-grasping power could be employed.

I determined, therefore, when arranging for the observations to be made during the eclipse of 1893, to renew the attack with the largest telescope and the greatest dispersion at my command.

The Solar Physics Committee was then in possession of a prismatic camera of 6 inches aperture. I decided, therefore, to employ it, all the more because the work on stellar spectra at Kensington had given abundant proof of its excellence.

THE ECLIPSE OF 1893.

The instrument was entrusted to Mr. Fowler, the demonstrator of astronomical physics in the Royal College of Science,

[1] *Phil Trans*, 1889, A, vol clxxx, p. 122.
[2] *Ibid*, p. 319.

who erected it at Fundium in West Africa, and obtained a series of photographs of the greatest value to science. A greater success has never been achieved in eclipse observations.

The object-glass of this instrument, corrected for the photographic rays, was constructed by the Brothers Henry. The correction is such that it is unnecessary to incline the back of the camera, and hence some of the objections which have been made to the use of this form of spectroscope are overcome. The large refracting angle of the prism (45°) obviously increases the value of the instrument for eclipse work.

The camera has a focal length of 7 feet 6 inches, and the spectrum obtained is about 2 inches long from F to K. Rings corresponding to the inner corona are about seven-eighths of an inch in diameter.

The tube is a strong mahogany one, square in section, and it was attached to the declination axis by means of a suitable iron plate. In order to reduce the weight of the instrumental equipment, the heavy iron pillar of the equatorial was replaced by a rough wooden stand which was filled up with concrete after being placed in position. Provision was made for the clock bracket and fine adjustments of the polar axis, and the whole arrangement was quite satisfactory.

Fig. 8 represents the instrument as adjusted for use in latitude 14° 3′ N. When actually at work, the camera was steadied by a stiff wooden rod screwed to the end of the tube, and bearing on the end of the declination axis; this did not interfere with the driving gear, and materially contributed to the successful results, as on account of the great weight of the prism it was necessary to bring a large part of the tube forward to the eye end. The brass cap which protected the camera from light other than that which passed through the prism and object-glass, is not shown in the diagram.

As time is very precious during an eclipse, every effort must

be made to economise it. I may therefore refer to the manner in which the photographic operations were facilitated by the dark slides used.

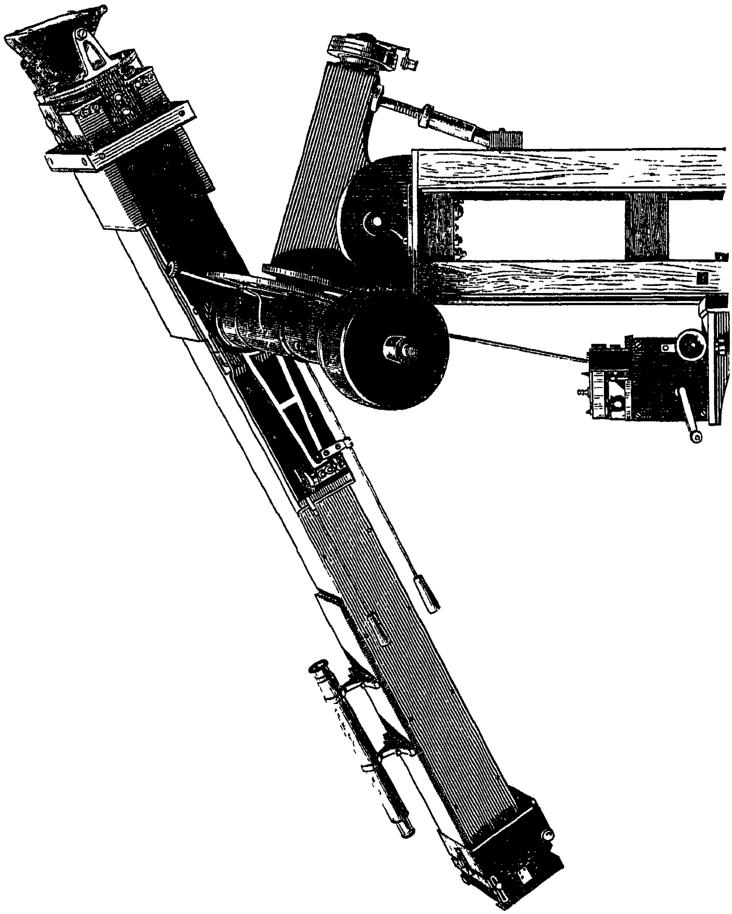

FIG. 10.—The 6-inch prismatic camera arranged for work during the Eclipse of 1893 (larger view).

The construction of the camera and dark slides, or plate-holders, was based on the plan which I devised for the large pictures of the corona which I hoped to obtain in the West

Indies in 1886. The slides are about 13 inches in length by 7 inches broad, and have three compartments, each taking a plate 6 inches by 4 inches.

The camera at the end of the long wooden tube has an opening 6 inches square, and a rectangular frame 24 inches long, with a central aperture 6 inches by 4 inches, and provided with grooves to take the slides, was symmetrically attached to it. A dark slide being placed in the frame, so that the first compartment was opposite the middle of the telescope tube, the shutter was then opened to its full extent, and an exposure made; the plate in the second compartment was next brought to the middle of the frame, by pushing the slide along, and also exposed: again, by moving the slide along, the third plate was brought into position and exposed, after which the shutter was closed and the slide withdrawn. During the exposure of any one of the three plates in a slide, the other two were protected from light by the rectangular frame.

The upper edge of each dark slide was notched in three places corresponding to the positions of the three plates which it contained, and as each plate came to the proper position for exposure, as the slide was pushed along, a spring catch automatically dropped into its place.

Upon the back of each dark slide six numbers were painted

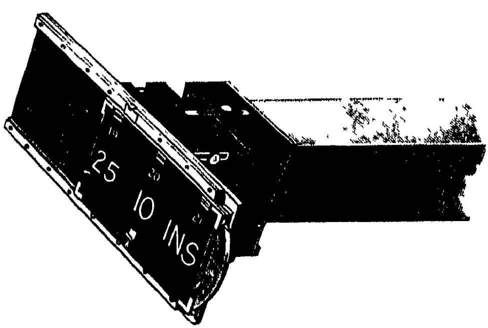

Fig. 11.—The dark slides used in 1893.

in clear white figures. The smaller series of numbers corresponded to the numbering of the thirty plates to be exposed during the eclipse, and the larger series indicated the exposures to be given to each plate, so that it was unnecessary to refer to any list.

These time-saving devices are of the highest importance in eclipse work, and too much attention cannot be given to them. The arrangements in West Africa worked admirably, and it was possible to change from one plate to another in about a second when a slide was once inserted, and to change the whole slide in five seconds. Longer intervals, however, were allowed to elapse between the exposures, in order that the instrument might steady itself, and to correct the backlash of the driving screw.

The instrument was focussed by photographing the spectra of some of the brighter stars. This is the only satisfactory method of focussing the prismatic camera, as rays from a star fall on the prism under exactly the same conditions as those from the eclipsed sun. If a slit and collimator be employed, identical conditions can only be obtained when the collimator is perfectly achromatic and absolutely adjusted for parallel rays.

I next come to the kind of result obtained by means of the unprecedented optical power employed in 1893, and for this purpose I reproduce two of the beautiful photographs obtained by Mr. Fowler.

It will be seen that we get more or less complete rings when we are dealing with an extended arc of the chromosphere, or lines of dots when any small part of it is being subjected to a disturbance which increases the temperature, and possibly the number of the different vapours present.

The interpretation of these photographs brings us in presence of many interesting and, at the same time, complicated problems. I do not, however, refer to them here, as they will form the subject of a subsequent chapter.

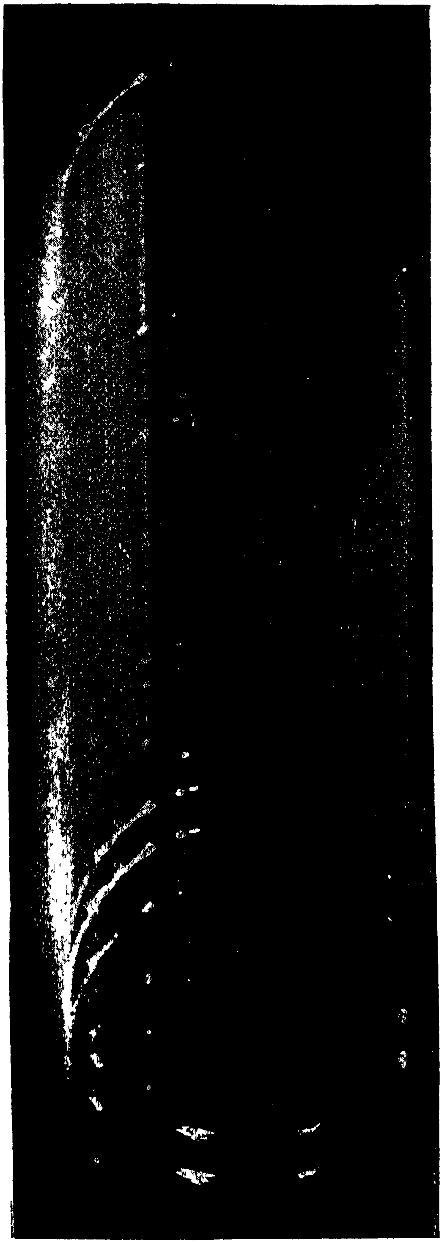

FIG. 12.—Untouched reproduction of photograph (African station) taken very shortly after the commencement of totality, the exposure being "instantaneous." At this phase of the eclipse a considerable arc of the chromosphere was visible, and its spectrum is therefore shown in addition to the spectrum of the higher reaches of some of the large prominences extending beyond the moon's limb. It will be seen that at H and K there are long arcs of chromosphere and prominences, the absent portions being of course obscured by the moon. One very small prominence is especially rich in lines.

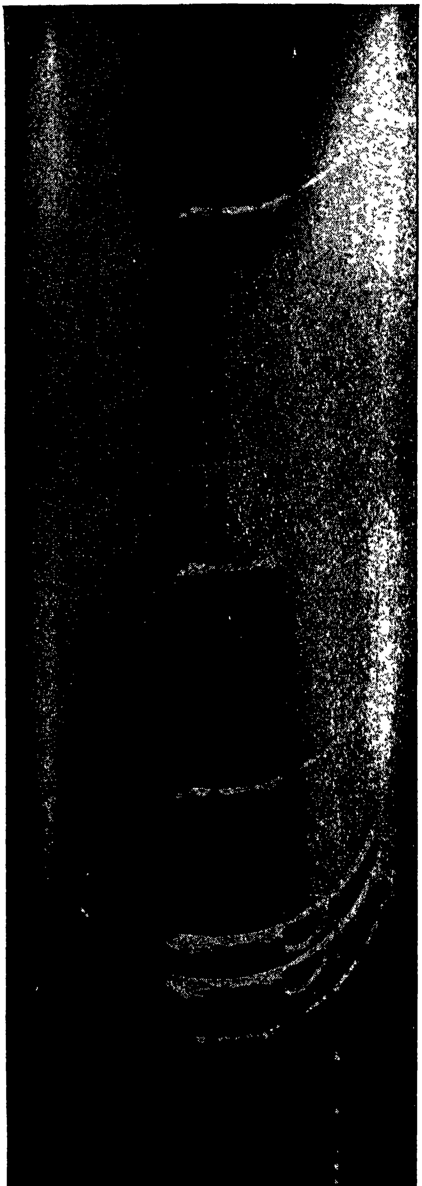

FIG. 13.—Photograph 21 (African station), taken shortly before the end of totality. A portion of the chromosphere on the other edge of the dark moon is now visible in addition to numerous prominences It will be seen that one of the smallest prominences is rich in lines, and that the spectrum closely resembles that which appears in FIG 12.

The instrument so successfully employed by Mr. Fowler was not the only one used in 1893. I had been able to equip Mr. Shackleton, one of the computers attached to the Solar Physics Observatory, with a large photographic spectroscope, deprived of its collimator, for use in Brazil. In this instrument we had two prisms of 60°. The object-glass was a Dallmeyer portrait lens 5D, aperture 3.25 inches, with a focal length of 19 inches. With this he was able to secure a second series of photographs.

The most important results recorded in 1893 may be stated as follows. We not only determined the wave-lengths with considerable accuracy of some 300 lines in the spectra of the chromosphere and prominences, and studied the distribution of the gases and vapour which gave rise to them, but the separation of the spectrum of the corona from that of the chromosphere was made perfectly clear.

CHAPTER VI—THE PRELIMINARY WORK IN LAPLAND IN 1896.

THE CHOICE OF A STATION.

WHEN it became a question of securing observations during the eclipse of 1896 on the lines laid down in the preceding chapter, at first the longer totality and higher sun in Japan seemed to make a station in that country most desirable, but a careful inquiry into the weather conditions showed the hopelessness of any attempt there, while, on the other hand, according to Professor Mohn, the weather chances in Lapland were excellent. I was then compelled to fall back on Lapland, and although it was true that the totality there was short, it had to be borne in mind that a short totality in the case of a prismatic camera is really more advantageous than a long one, for the reason that the rings are more complete; the longer the totality the shorter the arc impressed on each photographic plate.

The conditions of the 1896 eclipse, so far as Europe was concerned, may be gathered from the accompanying map, reproduced from that communicated to the Royal Astronomical Society by Colonel Burton Brown, R.A.

It will be seen that the eclipse track struck across Norway from the West Coast to Vadsö, near the N.E. corner. The latter region was preferable as an observing station, because the sun was higher and the eclipse lasted longer there.

The accompanying large scale map of the Varanger Fjord to

the N.E of Norway, showing the region round Vadsö, has been photographically reduced from the Admiralty chart.

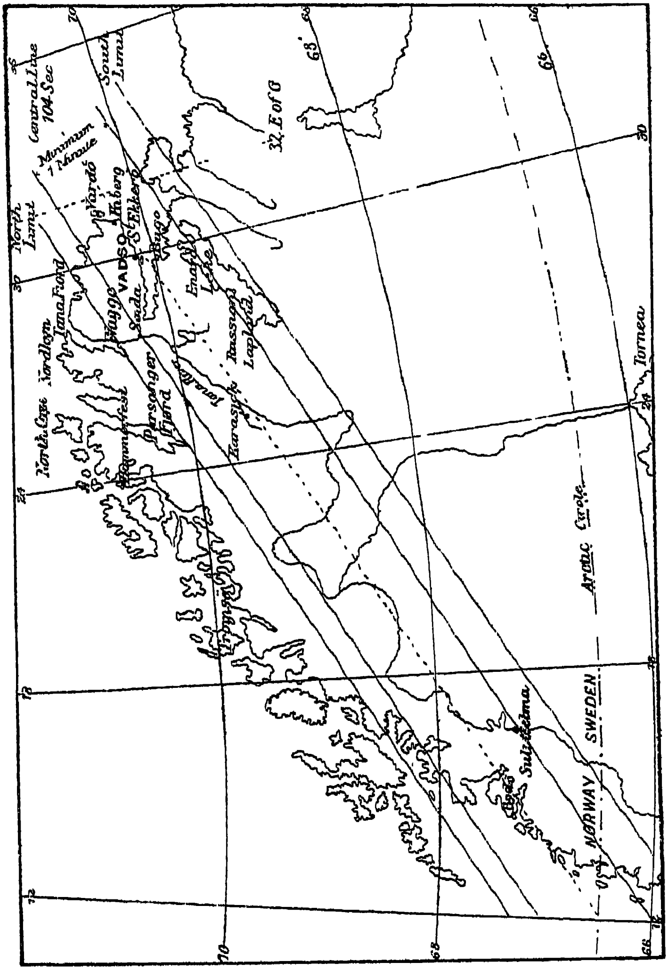

FIG. 14.—Map of Northern Norway, &c., showing line of shadow during total eclipse of the sun, 9th August, 1896.

Mr. Crommelin had communicated to the *Journal of the British Astronomical Association* a diagram showing the relation of the sun's axis and equator, and the path of the moon's centre

to the horizon at Vadsö (Fig. 16). This, by the courtesy of Mr. Crommelin, is reproduced here.

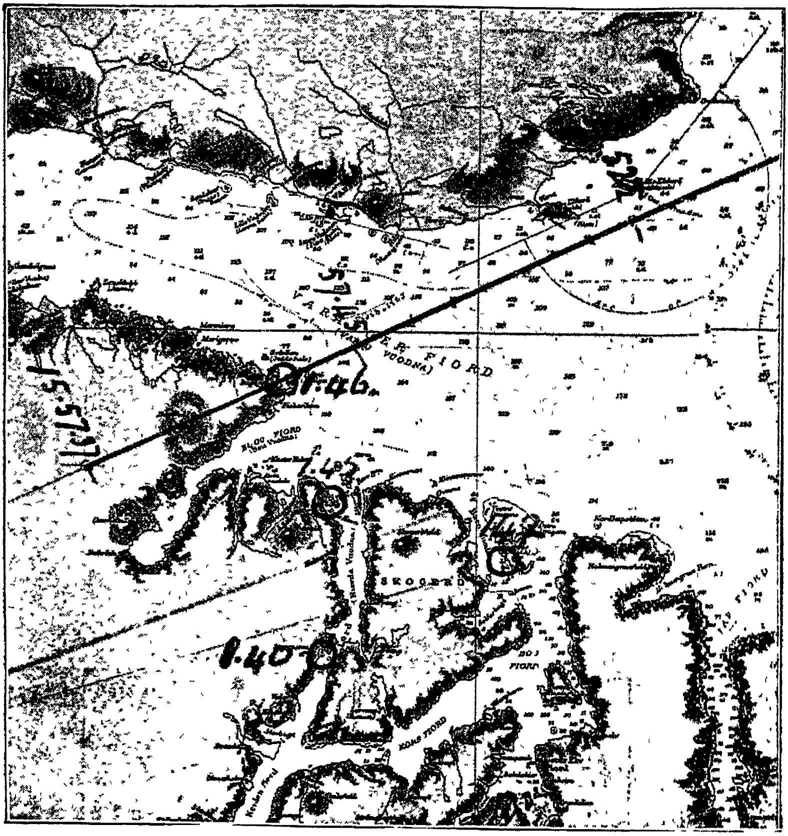

FIG. 15 —Chart of the Varanger Fjord, showing duration of totality.

Kiö Island was eventually chosen, as the superiority of a station south of the fjord, and the importance of a low lying site were insisted upon in the local information obtained.

Very many inquiries were made at the various stopping-places in the north of Norway concerning the chances of fine weather in the neighbourhood of Vadsö. The English Consul

at Hammerfest, where H.M.S. "Volage" picked up Mr. Fowler and Dr. W. Lockyer, informed them that the question of clear or foggy weather depended almost entirely on the direction of the wind. An east wind at Vadsö meant foggy weather, a west

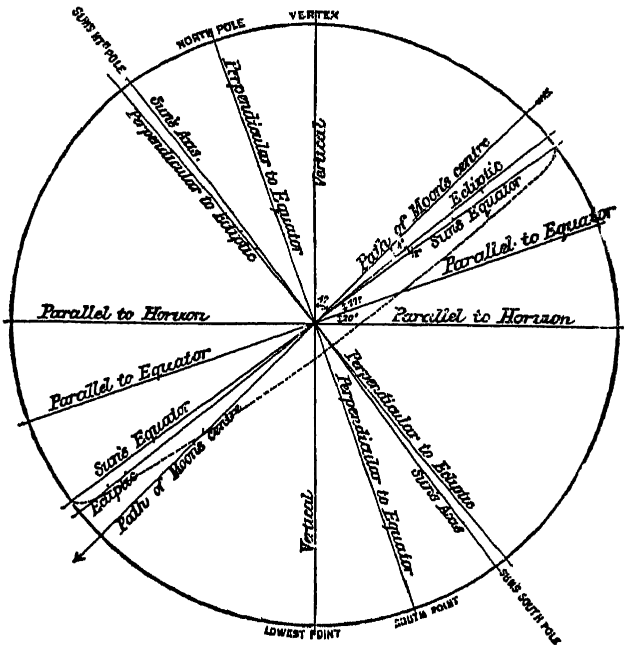

FIG. 16.—Conditions of the Eclipse at Vadso in 1896.

wind fine; the reverse was the case at Hammerfest. It was also mentioned that the south side of the Varanger Fjord seemed to be more free from fogs than the northern shore. It was also made manifest that it would be unwise to select an elevated spot, since clouds and mists often were seen hanging about at 100 feet and over, while the lower levels remained clear.

The experience, gathered from the first few days spent on the

southern shore, did not, however, bear out very exactly the Hammerfest information. The 24th and 25th were both miserably wet days, and yet the wind was blowing hard the whole time from the north-west. The following two days were very fine and hot, the wind coming from the eastward. But the view as to the necessity of a low elevation was quite justified from the first.

When mists were prevalent, Kio was always better off than the surrounding country. The hills to the south-east and south-west have often been wrapped in mists, while the eastern horizon at the camp was as clear as a bell.

The weather to begin with seemed to have a two-day period, two fine days following wet days. The 29th and 30th were wet and windy days, while the two following ones were moderately fine. On the s.s. "Garonne," in which I had travelled to Vadsö, I had an opportunity of consulting two pilots well acquainted with the Varanger Fjord, and both informed me that the characteristic feature of the weather was that the mornings were fine and the sky was overcast later. This in the main proved accurate. The eastward horizon (we had a sea horizon at the camp) was nearly always clear in the earlier part of the morning, *i.e.*, about 6 A.M., while towards 6 P.M. it was invariably cloudy. This gave us good encouragement, and made our chances of fine weather at the time of the eclipse very hopeful.

Since many observers had determined to occupy the north side of the Varanger Fjord, it seemed a duty to go to the south side, where the weather chances were bound to be about the same. In this case, however, a man-of-war was necessary as a base. This was a matter of utmost congratulation, for I knew how surely help could be depended upon, even in extending the area of observations.

Thanks to the intervention of the Royal Society, H.M.S. "Volage," commanded by Captain King Hall, was ultimately

detached for this duty, and my story will be very badly told if I fail to show what a debt of gratitude science owes to him and his ship's company for what they did in the hope of securing such a record of an eclipse as has never been attempted before at a single station.

FIG. 17.—The landing of the exploring party.

On July 23, then, H.M.S. "Volage," coming from Iceland with most of the instruments on board, picked up at Hammer-

fest Mr. A. Fowler and Dr. W. J. Lockyer, who had been sent forward to erect and adjust them.

On the evening of the 24th the "Volage" arrived some seven miles south of Vadso, and proceeded to land a party of explorers to find a suitable site for the encampment on the south side of the Varanger Fjord, which had been determined on, and also to make a survey of Bras Havn in order to find the most convenient anchorage.

After sending the party on shore, Capt. King Hall proceeded to Vadso to communicate with the Governor (the Norwegian Government had already given permission to camp) as to the local weather conditions. The landing party, which consisted of Lieutenant Martin and Sub-Lieutenant Beale, Mr. Fowler, and Dr. W. Lockyer, and several bluejackets, together with Lord Graham, who had volunteered to help, proceeded to the shore in the steam cutter, having in tow the sailing cutter and the dingy, and provided with the necessary coal, water, and provisions for two days. During the three-quarters of an hour steaming from the ship they encountered a sharp squall, which would have saturated everybody if it had not been for the invaluable sou'-westers and oilskins; and it is well here to note that if one goes to the north of Norway, these should always be found in the kit together with a pair of sea-boots.

The party landed, however, safely on a small island on the eastern shore of Bras Havn, and commenced immediately to put up tents. By 11 P.M., local time, all preparations were finished. The evening turned out so beautiful that a chat round the camp fire and a drop of grog were indulged in before turning in.

The first morning on this island was not by any means cheerful, rain was coming down in torrents, and the wind whistled round the tents in a most unwelcome manner. It was decided that the survey of the bay should be taken in hand first, so Lieutenant Martin, Sub-Lieutenant Beale, and Lord

Graham started off in the steam cutter and commenced operations. The weather did not improve, but rather the reverse; the survey, however, made good progress notwithstanding the unfavourable conditions, but all hope was given up of finding on that day a site for the observatory on the island near by.

Sunday morning was of a different type, and work was commenced at an early hour. Mr. Fowler and Dr. W. Lockyer were landed on Kiö Island while the survey was being finished.

The island of Kiö lies nearly north of Bras Havn, at a distance of about a mile and a quarter. The island itself is small, and consists of gneiss *moutonné* and polished to a wonderful degree, the surface putting on the appearance of snow in many places. The rock is covered here and there with peat. At the first glance it seemed that a suitable site for the observatory was out of the question, but, on examination, a very fair spot was selected which appeared to improve the more acquaintance was made with it.

THE ERECTION OF THE OBSERVATORIES.

So soon as the site for the Eclipse camp was decided on, to economise time the best places on which to erect the concrete pillars were selected, and pits were dug in the peat to sound for the solid rock.

With the evening came the "Volage" from Vadsö, and her arrival was gladly hailed by the whole surveying party, as provisions had run rather short, and peat water was not regarded as a luxury. The return of the ship meant that work could now be begun in earnest, so plans were laid for an early start on the morrow. Fortunately the day proved fine, and a commencement was made by putting up the hut for the 6-inch prismatic camera. This is the time when a war-ship at one's back makes everything easy. The gunner turned bricklayer for

the occasion, and commenced, with the help of a couple of blue-jackets, mixing and setting up concrete pillars for the 6-inch and siderostat. The ship's carpenters, with their assistants, went to work with zeal at the erection of huts. Others were

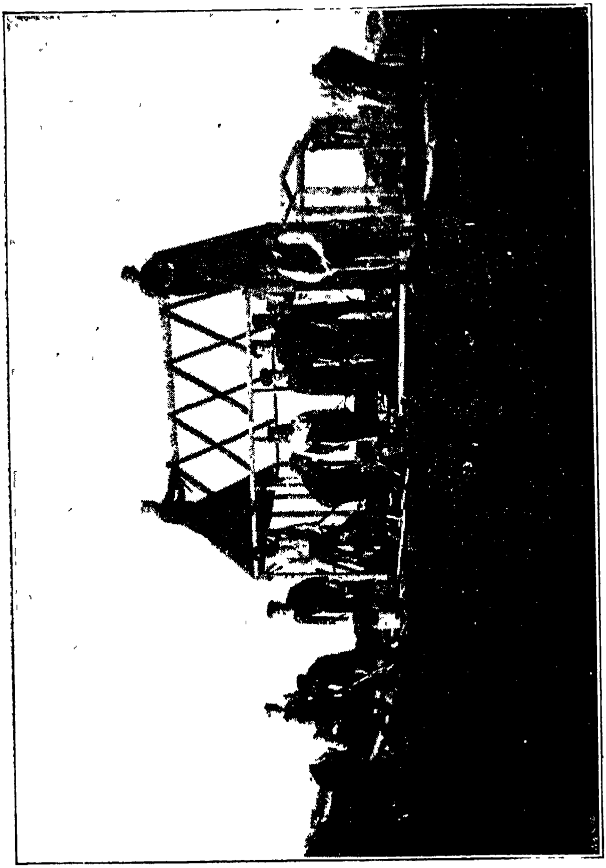

FIG 18—The erection of the huts

employed in fetching from the beach sand and stones, which were required for the concrete pillars.

Levelling the camp occupied also the time of another half-dozen bluejackets. At the close of the day's work the appear-

ance of the spot had entirely changed, and the Lapps who came and watched the work seemed to be very much astonished at the alterations taking place on their island. They were, however, very friendly, and seemed to be only too pleased to help in any way they could; their assistance, however, was not required, as sufficient was at hand.

The following day, which proved fine, saw even greater progress; for besides erecting the 6-inch prismatic camera and siderostat, a party of bluejackets was employed in carrying stones from the beach to place on the peat covering the floor of the camp. This was done in sailor fashion, and at the word of command "stone camp," the small path leading upwards to the camp was lined with bluejackets, and buckets, full and empty, were passing up and down respectively. The scene was an interesting one to watch, and, after two hours' work, a geologist might have found a genuine raised beach.

Bad weather, however, now set in, so work was restricted for the next two days mostly inside the huts. The integrating spectroscope was put together, photographic dark slides were blackleaded to run more easily in the grooves of the cameras, and two more tents were put up to protect the 9-inch prismatic camera and integrator from the weather. The latter was composed of ship's materials, a sail being used for the covering; the tent served its purpose well, and withstood, like the others, a heavy blow from the east.

The two wet days were followed by two very fine ones, and great advance was made.

The foregoing account will give an idea of the kind of work done up to the end of August, the day of my arrival at Kio. It was impossible for me to join the advanced party, so I subsequently proceeded direct to Kio in the Orient liner "Garonne." After a delightful voyage through the most wonderful of the Norwegian fjords under perfect travelling conditions, Captain Veale was good enough to slightly alter his course so as to drop

me and my gear at a point about two miles north of the island, where I was met by the boats of H.M.S. "Volage," which soon transferred the rest of the instruments and myself to the Eclipse camp.

It will have been gathered that when I arrived at Kio, all the fixed instruments brought out had been erected and adjusted *as far as possible,* I put in this qualification because, of course, all star observations were out of the question, as the sun at midnight was only 4° below the horizon.

Furthermore, profiting by the good will and keenness to assist on the part of the officers, full complements of assistants had been secured for the various manœuvres requisite to obtain the greatest amount of results in the restricted time covered by the totality.

The Volunteers.

But Captain King Hall was not satisfied with this contribution to our endeavours. He inquired whether the services of other volunteers would be of any help to us. I replied that there was so much to be done that I thought I could usefully occupy all possible volunteers if the detail of duty on board left any time for instruction and training. I was at once taken at my word, and was requested to give, in lecture form, that evening a statement of what was required, and why it was useful to try to do it. This was done by the help of the magic lantern, which had been kindly lent me by the "Garonne," the deck forward being darkened by sails laid over booms. After it was over the Captain called for volunteers Many at once responded to the call, and, to make a long story short, I may say that soon the number of volunteers, including officers and men, was over seventy.

The "Volage," as one of the Training Squadron, carries a large complement of officers, and especially young officers.

FIG. 19.—The officers of H.M.S. "Volage."

FIG. 20.—Volunteers to the front.

Every one of these officers was included among the volunteers, some for observations ashore, some on board.

The first thing to be done next morning with this wealth of help was to set to and prepare a programme of eclipse work beyond all precedent.

It was at once determined to form groups to sketch the corona, to note the stars visible during totality, to note the changes of colour of the landscape, discrimination being made between cloud, sky, and land and sea surfaces; to erect several discs cutting off the lower corona to different heights; and the swoop of the shadow of the moon was not neglected.

Further, as I had brought small polariscopes, prisms, and slit spectroscopes with me, other groups evidently had to be formed to use these instruments.

Two things then obviously had to be done at once—to select the artists, and to start some spectroscopic demonstrations among the more scientific-minded. Captain King Hall at once gave up his fore cabin for the one, and Staff-surgeon Whelan lent spirit-lamps for the other.

The corona drills were most interesting and, I think, important.

I had no telescope available for obtaining photographs of the corona, so I was forced to rely on drawings, which experience shows are better than photographs for feeble extensions, although it is the fashion to ridicule them. I am free to confess that often there has been no resemblance between such drawings taken at the same place; still, all the eclipses I have seen have had coronas of very different forms; and further, the special features I recorded by eye during the eclipse of 1878 were confirmed by the photographs. It seemed possible, therefore, that the want of agreement came from want of practice under eclipse conditions.

On my way to Kio, therefore, I determined to make an experiment, by the kind help of several of my shipmates on the

Orient liner "Garonne," to see how much the uncertainty of the result depended upon the absence of special training, and to what extent it could be eliminated.

With this object in view, by means of a capital magic lantern which we had fortunately on board, I threw on the screen about a dozen photographs and drawings, coloured and otherwise, of various eclipses observed since 1869, describing the main points to be noted at the sun's poles, equator, &c. Finally, I threw a previously unseen corona on the screen, marking the time—I took 105 seconds—as during an eclipse.

It was amply proved that after two or three drills of this kind all the drawings were wonderfully similar.

This new bit of experience therefore showed that when made under good conditions such drawings become of the utmost value, and the best possible conditions were present on the "Volage," with her thirty-five volunteer sketchers.

The first competition among the volunteer artists took place at 9 p.m. on Tuesday, 4th, and was repeated each night afterwards. Ten marks were given for form, ten for colour. As on the "Garonne," after a brief description, with photographs on the screen of the things to be looked for, and the lie of the sun's axis to the horizon of Kio, a previously unseen coloured drawing of the eclipse of 1869 was thrown on the screen, and the 105 seconds given out in proper eclipse fashion by means of a stop-watch. This was followed by a copy of Langley's drawing of the eclipse of 1878. The similarity among the drawings on both occasions, and the accuracy of the notes on colours were truly marvellous; many full marks were accorded, and as a result sixteen of the sketchers were secured for the drawings of the corona, eight for the colours of the landscape, and four for observations of the moon's shadow.

For the disc parties there were six volunteers, Captain King Hall himself taking charge of the first. For this work keen eyesight was, of course, of the first importance. The drill I had

suggested for the officers of the Training Squadron was adhered to, the real observer being blindfolded till ten seconds after the beginning of totality.

Of the spectroscopic classes little need be said; they included nine volunteers.

The distribution of work among the party was finally as follows:—

Fixed Instruments.

1.	6-inch prismatic camera	5
2	9-inch " "	6
3.	Integrating spectroscope	4
4.	Discs	6
5.	6-inch grating spectroscope	6

Other Observations.

6	$3\frac{1}{4}$-inch telescope	2
7.	Sketches of corona	16
8.	Colours of landscape	8
9.	Moon's shadow	4
10.	Slit spectroscopes	4
11.	Prisms for rings	2
12.	Polariscope	2
13.	Timekeepers	3
14.	Contracts	4
15.	Thermometers	6

Thus making a total of 78

Three main stations were next fixed upon: Kiö, as head-quarters; an island lying between Kio and the "Volage," on which a signal station had been erected to convey messages to and from the ship; and finally the top of the majestic cliff near which the ship was lying

Before I pass from this part of the subject, it may be stated that the volunteers not only included all the officers but comprised petty officers and men of almost every rating.

This is clearly shown by the following copy of the muster roll prepared and handed to me by the Rev. E. J. Vaughan, the Chaplain of the "Volage."

TOTAL ECLIPSE EXPEDITION AT "ECLIPSE" ISLAND, VARANGER FJORD, AUG. 9, 1896. H.M.S. "VOLAGE," TRAINING SQUADRON, ASSISTING.

Aide-de-Camp to Mr Norman Lockyer.
Mr. Hugh B. Mulleneux, Midshipman.

1. *6-inch Prismatic Camera.*
   Mr. Fowler.
   Lieut Beale.
   Geo Roberts, A.B.
   Private Fras. Huskisson, R.M.L.I.
   Private Joseph Briggs, R.M.L.I.

2. *9-inch Prismatic Camera.*
   Dr. Lockyer.
   Mr. Fitzwilliams, Mid.
   Mr. Bruce, Mid.
   Patrick Sullivan, Lg. Shipwrt.
   Harry Froud, A.B
   Alfred Woollard, A.B.

3. *Integrating Spectroscope.*
   Lieut. Martin.
   Mr. Silvertop, Mid.
   Mr. Woodbridge, Mid.

4. *Discs 3′ and 5′.*
   Capt. King Hall } 3′ Eclipse Island.
   Mr. Parker, Mid. }
   Fredk. Hesch, P.O. 2 Cl. } 3′ Signal Island
   William Bowden, P.O 1 Cl }
   Thos. Bridgeman, P O. 2 Cl. } 5′ Eclipse Island.
   John Hilyard, Qual. Sig. }

5. *Sketches of Corona*
   Mr. Constable, Mid.
   Mr. Greene, Mid
   Mr. Warton, Mid.
   Thos. Sutherland, S. Corpl.
   Archd. Wright, 2 Yeo. Sig.
   Edwd. Marshall, Boy 1 Cl.
   Robert Roberts, Boy 1 Cl.
   William Hicks, Qual. Sig.
   Chas. Miles, P.O. 1 Class.
   Chas. Bennett, S B. Attendant.
   Edward Miller, P.O. 1 Class.

James Biss, Boy 1 Class
Willm. Barton, Ord.
Joseph Gale, P.O. 1 Class.
Edward Pegler, Lg. Sig.
Cuthbert Davis, Lg. Sea.

6. *Colours of Landscape.*
Lieut. Sinclair. On board " Volage."
Staff Surgeon Whelan Signal Island.
Lieut. Yelverton.
Harry Beresford, Yeo. Sigs.
Harry White, Ch. Stoker. } Eclipse Island.
Geo. Bennett, Lg. Seaman.
Herbert Gambler, A.B.
James Harding, Stoker.

7. *Shadow Phenomena*
Private Geo. Allen, R.M L.I.
Private Frank Blanchard, R.M.L I.
Private Thos. Gauntlett, R.M.L.I.
Richard Collings, Blacksmith.

8. 6-*inch Equatorial with Grating.*
Mr. Fowler. } First and last contacts.
Lieut. Clinton Brown.
Mr. Norman Lockyer.
Lieut Clinton Brown. } During totality.
Mr. Brooks, Asst. Paymr.
Rodney Munday, Sig. Boy.

9. $3\frac{1}{4}$-*inch Telescope.*
Mr. Norman Lockyer
Lieut. Hodges.
Henry Lewis, Writer.

10. *Slit Spectroscopes.*
Lieut. Law.
Chas Smith, Boy Writer.
Thos. Makepeace, Ch E R.A.
Willm. Westacott, Sig.

11. *Prisms for Rings.*
Alex. Duncan, E.R.A.
Thomas Brown, E.R.A.

12. *Timekeepers.*
William Smith, P.O. 1 Cl.
Alfred Saunders, P O. 1 Cl.
Mr. C. E. Lloyd Thomas, Mid. (Chronometer).

13 *Contacts.*

1–4 Staff Paymaster Ramsay.
Staff Engineer Underhill. } Signal Island.

1–4 Mr. Fowler
Lieut. Clinton Brown. } Eclipse Island.

2nd. Mr. Norman Lockyer.

3rd. Mr. Norman Lockyer.

14. *Polariscope.*

Rev. E. J. Vaughan, M.A., Chaplain.
Rowland Allison, Armourer's Crew.

15. *Meteorology* (Thermometers).

John Yardley, P.O. 2 Cl.
Chas. Symes, P.O. 1 Cl.
Fred Faizell, Stoker.
Willm. Thripp, Stoker. } Eclipse Island.

Ernest Hurst, P.O. 1 Cl.
T. Cannon, Lg. Sig. } Signal Island.

16. *Stars.*

Rev. E. J. Vaughan, M A.
Lieut. B. Yelverton.
Lieut. Hugh F. Sinclair.

17. *Landscape Camera.*

Marquis of Graham. Eclipse Island.

18. *Observations of Shadow Bands.*

Staff Surgeon Whelan, M D. Signal Island.

CHAPTER VII.—THE EVE OF THE ECLIPSE.—A LETTER FROM KIÖ.

KIÖ ISLAND, *August* 8.

A LOVELY morning. The sun remained unclouded till long after eclipse time, giving thereby an additional proof of the advantage to us of the short nights There is no time either for any considerable reduction of temperature or for the accumulation of any great amount of moisture in the air; hence unclouded sunrises, and the sun strikes hot soon after rising. The beautiful harbour in which the "Volage" is lying looks its best in early morning.

I am glad to say that the last adjustments have been made, the last demonstrations given; numerous rehearsals have landed us in the perfection of drill; the parties all know their stations, and all necessary forms have been written out. We are going then to-day to "stand easy," and take some rest in preparation for the fateful to-morrow.

I confess I am keenly interested in our now tremendous eclipse party. I will first of all, then, deal with its progress, and especially with the final arrangements made for the larger instruments.

The *personnel* of each fixed instrument is as follows. Mr. Fowler has charge of the 6-inch prismatic camera, and he has the following assistance.

As timekeeper Sub-Lieut. Beale offered his services, and his

duty is to give Mr. Fowler warning some seconds before the commencement of totality, and to record the times of exposure of the fifty plates intended to be used. Roberts, an A.B., acts as exposer, taking off the cap from the prism at given signals.

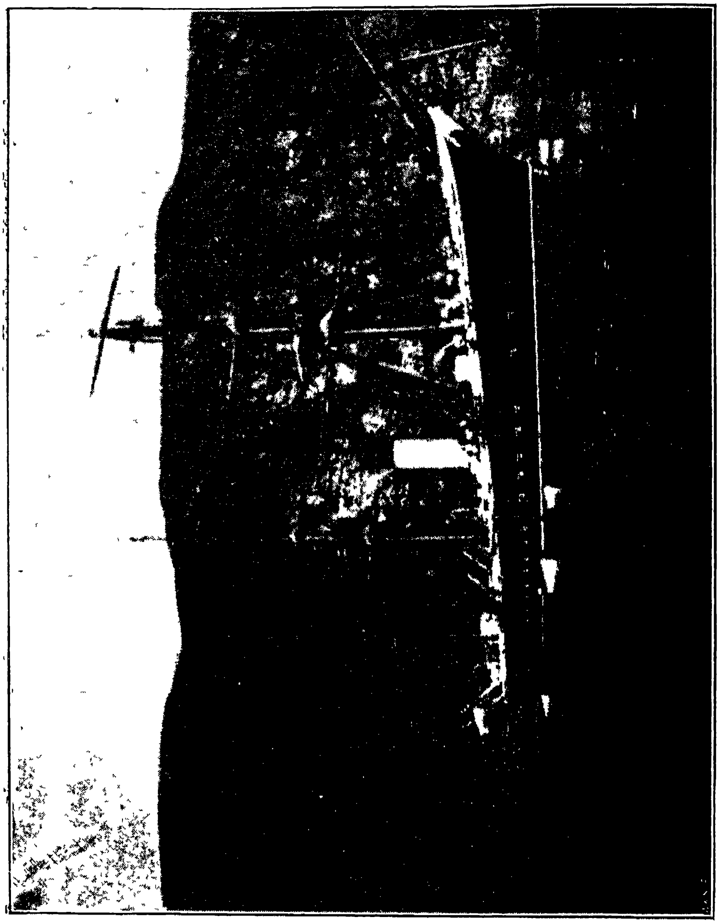

FIG 21.—H M S. "Volage" at anchor.

To economise the greatest amount of time, two marines stand to Mr. Fowler's right and left, to hand and receive the slides as they are inserted in and drawn out of the camera. The

exposures to be made are generally very short, in fact they are all snap-shots with the exception of only two, one of these extending to half a minute.

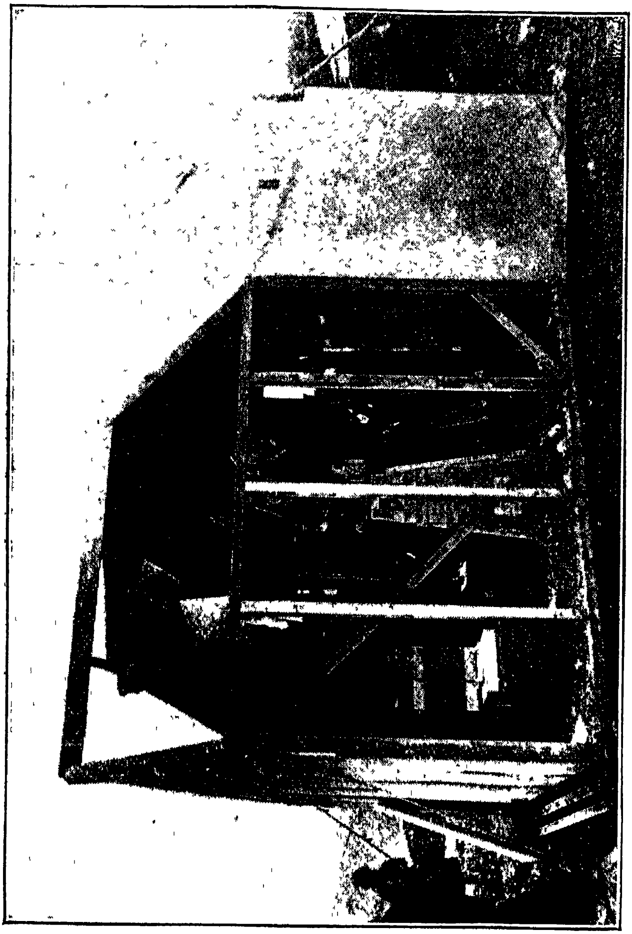

FIG. 22 —The 6-inch hut, showing Mr Fowler and his assistants at drill.

The plate-holders are ten in number; each is capable of holding five plates, which are exposed by slipping them in turn into the focal image; this operation is controlled by a catch. The hut in which this instrument is housed is one

brought out from home, the framework is covered with waterproof canvas so arranged that the roof can be removed at any time for observation. A dark room for photographic work is also attached.

FIG. 23.—The siderostat and the 9-inch hut.

The instrument under the charge of Dr. W. Lockyer is also a prismatic camera, but of 9 inches aperture, and rather differently mounted. The tube carrying the camera, prism and lens is

fixed horizontally, and the light is thrown on to the prism by means of a siderostat.[1] The work intended to be done is to obtain ten photographs in all; two snap-shots, seven with different times of exposure, the greatest amounting to thirty seconds, and lastly, a "dropping" plate. This last-named is intended to be exposed as near as possible ten seconds before the end of totality, and carried through until fifteen seconds after, the plate being moved slowly in the direction at right angles to the length of the spectrum The object of this motion is to obtain an unbroken record of the changes in the spectrum during this interval of time. As timekeeper Midshipman Bruce has been selected, his duty being to keep Dr. W. Lockyer informed of the time a few seconds previous to totality, and also to note the times and lengths of the exposures made during totality. One of the ship's carpenters, Sullivan, operates with the cap in front of the prism, acting on instructions given to him by the observer. Two bluejackets are also employed in handing and replacing the dark slides as they are required.

The whole work of using the integrating spectroscope[2] is left to members of the ship's company. Lieut. Martin has been selected as director, and he has as his assistants Midshipman Woodbridge as exposer, Midshipman Brendon as timekeeper, and Midshipman Silvertop to keep the sun's image on a small screen for the purpose of correct orientation.

The instrument is set up on a board inclined at the angle representing the altitude of the sun at the time of eclipse, and movable in azimuth by means of a milled-head-driving screw turned by hand. By this means the collimator can be continuously pointed towards the sun, which does away with the necessity of using a second siderostat, and this is all the more important because we have not a second siderostat. The intention is to make three exposures with this instrument.

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[1] See note, p. 87. [2] See note, p 142.

The whole apparatus is housed in a tent made by the carpenter out of ship's material, spare spars and a sail. The peculiar appearance of the hut has resulted in its being named by the

FIG. 24.—The integrating spectroscopic camera.

sailors Porcupine Cottage. The hut for the 6-inch, which adjoins it, is called the Town Hall.

With regard to the other branches of work, in some of which

the numbers assisting are large, the senior volunteer in each has been made responsible for the preparation and subsequent signing of forms, and representative in general of the party. The Chaplain, the Rev. E. J. Vaughan, whose interest has been unflagging throughout, has been good enough to act as intermediary between these representatives and myself, so that the closest touch has been kept. It was thought desirable that in addition to acting on the general instructions, each party should know the special points on which information is desired. A request for detailed answers to certain questions has been therefore placed in the hands of the head of each section.

I have said that this morning was lovely; yesterday—the 7th—was not by any means a pleasant and bright day, but the rain managed to keep away and allow work to be carried on in the camp, in which the preparation and the rehearsals have been vigorously continued. The first boat leaves the ship at about five each morning, so as to secure drill at eclipse time, and from this onwards there is a continual passage of boats from ship to camp and back again, as the various observers are released from their work, which goes on incessantly, not only on board among the guns and masts, but in the fjord, in the shape of firing and boat parties, the firing being strongly objected to by the inhabitants of the "loomery," which is hard by.

The birds, which in our stay we have become acquainted with, are of several kinds. Foremost among these is the white seagull, which has its home on the crags and ledges of the cliff to the west of the "Volage." These birds literally swarm here, but apparently seem to be divided into distinct societies; indeed, on the cliff there are three or four separate "loomeries," and the birds in each of them always keep together and seldom, if ever, intermix with those in others. At apparently fixed times they fly down from their ledges and form a teeming, hurrying, clamorous throng, eddying in front of the face of the cliff. The young birds at the time are just beginning to fly, so the noise is

perhaps greater than usual. After we had been here a few days they all became very tame, and swam round the ship. On Starvation Island several young ones were found; these could be easily located by paying attention to the utterances of the parent birds flying overhead, which became louder and louder the nearer the right spot was approached.

The young birds were found always in small pools between the rocks, generally lying under small bushes of grass overhanging them. The bluejackets, when ashore, caught many in this way, and it was amusing to see these birds walking about the forecastle as if owners of all they surveyed. An amusing incident occurred on the evening the "Volage" arrived from Vadsö. Lieutenant Martin and Sub-Lieutenant Beale, on going on board the sailing cutter, found a dead gull in the bottom of the boat; on further examination no less than twenty to twenty-five more were found stowed away in the stern. On making inquiries of the bluejackets as to their presence, they replied that they had collected them for supper in case the ship did not arrive that night, as provisions were rather short. The ship, however, did arrive, so that fried gull was not indulged in.

The shag, or green cormorant, abounds also in great numbers. These birds are far from beautiful, and were disliked by everybody. Many of them were too fat to fly properly, and when disturbed they managed to make themselves scarce by flopping over the surface of the water. The reverse was the case with the prettily marked oyster-catchers, these were always watched with interest, and there were five which greeted the party daily as it landed on Kio Island. These birds are noted for being very self-possessed, cautious, and deliberate, but any event out of the ordinary arouses their curiosity, and incites them to make closer examination. Of the other birds seen, some were quick-moving sea-swallows, and a few ducks swimming occasionally along the fjord.

On our island, Kiö, there are several Lapps who continually watch our movements. In the small bay on the western shore there is one small hut in which about five, including one woman, live; while generally some of the others encamp in

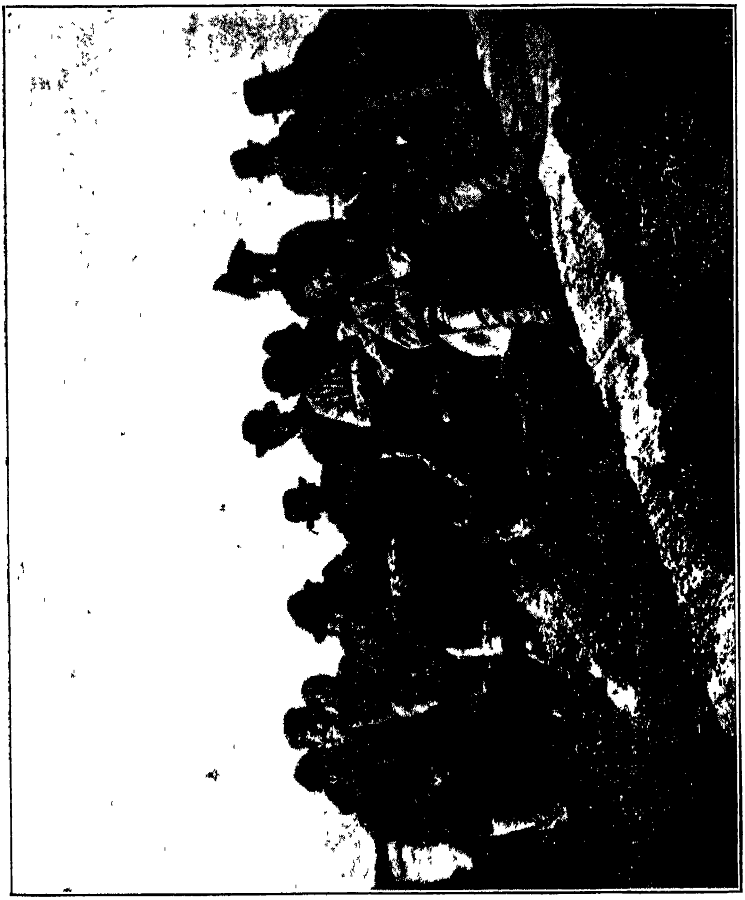

FIG 25.—Our Lapp visitors.

small curiously looking huts near by, or else sleep in their boats or on skins ashore. In the bay to our south-east, on the other side of the fjord, there is quite a large Lapp encampment,

and it is from this that most of our visitors come. The accompanying group shows many of these. This photograph was taken instantaneously, and without any preparation as regards grouping, and shows them as they sat watching us erecting the huts and instruments. At this time of the year they are generally occupied in fishing, and they sometimes bring up very fine selections of fish to our camp, which are generally bought by the steward for the ship's mess. The peat also on the island had been cut and stacked, so that this also formed at an earlier period of the year part of their daily work.

We are quite out of the world here, and till yesterday had no information as to what the other parties were doing at Vadsö. We knew that the remaining ships of the Training Squadron had arrived on Wednesday, and the booming of salutes from time to time informed us that other men-of-war had arrived. We could get no information concerning the astronomical parties, and no observer could be spared to make inquiries.

But late on Tuesday, when we had finished sketching drill, and were experiencing our only fog, a syren and the quick reply of the ship's bell told us that some vessel was approaching. Shortly afterwards we made out one of the small steamboats which ply from Vadso to the fjords on the south side; she subsequently came alongside. We saw that Dr. Common and Sir R. Ball were on board, and I hailed them from the poop. Captain King Hall hospitably invited them on board, but the invitation was declined owing to the weather conditions, which were not improving, and the lateness of the hour. They had still to run 12 miles to reach Vadso.

Captain King Hall invited Dr. Common, Sir R. Ball, and Mr. Downing to come over from Vadso yesterday to lunch and see our camp. Dr. Common was too busy in setting up and adjusting his instruments, but Sir Robert Ball and a small party paid the ship a visit. We had previously arranged that

the final dress rehearsals should take place in the afternoon, so our visitors were just in time to see the drill gone through. All timekeepers, chronometer, stop-watches, and deck watches were ready. Each man was at his appointed post; the sketchers stood to the west of the camp on the higher ground, the disc observers were blindfolded and in their places, while each of the other instruments was attended by its full staff. These rehearsals must appear very curious to those unacquainted with eclipse work, and certainly our visitors saw the very perfection of drill. The routine gone through was exactly the same as if the eclipse was taking place, with the exception that no plates were actually exposed. After these general rehearsals the observers at each special instrument were put through their facings. Our visitors seemed to be rather astonished at the great amount of work that will be done if the weather only proves favourable to-morrow.

We gathered from Sir R. Ball that all the arrangements at Vadsö were nearly complete, and that Dr. Copeland's 40-foot tube was already in position.

The time arrangements have to be somewhat complicated, for the reason that it is desirable to begin the exposures with the prismatic cameras ten seconds before totality. We have then, if possible, to make a correction should the *Nautical Almanac* times be slightly out. The Admiralty authorities were good enough to put on board at Portsmouth a first-rate chronometer for our special use, and Lieutenant Martin and Sub-Lieutenant Beale have been unremitting in their endeavours, by taking sights and noting rates, to give us G.M.T. within a small fraction of a second.

Before totality we have two chances of checking the *Nautical Almanac* times, by observing the first contact spectroscopically, and, failing this and more doubtfully, by observing the crescent when it covers an arc of 180°, this, it has been calculated, should occur seven minutes ten seconds before totality. My

intention is before totality, in case we miss the first contact, to set one of the stop-watches going when the crescent covers as near as may be 180° of arc.

It has been arranged that after the first contact the true G.M.T. will be called out from time to time as required, and also each minute before totality, corrected, if necessary, in the manner I have stated. In this way the special timekeepers of the prismatic cameras will be able to begin their work at the right moment before the general signal for totality, "Go," is given.

I am sorry to say that the eclipse-clock has broken down: the ship's armourer has vastly improved its going, but it has received some damage, so that I cannot rely on it. It is not good for a clock to be used only once in five years or so! So we fall back on stop-watches, and here I must state my obligations to Mr. Tripplin for the loan of a fine chronograph, which makes our stock complete, and enables us to feel certain that at one station or another the exact duration of totality will be caught.

One of these stop-watches will be handed to our two excellent timekeepers to replace the eclipse clock.

Two things have been strongly impressed upon me in my eclipse experience. The first is always to arrange the work so that everybody can have thirty seconds in which to observe the phenomena of the eclipse with the naked eye; the second, to take out no case which weighs more than 50 or 60 lb.

The importance of the first was forced upon me in 1871, when Captain Bailey, who travelled 400 miles to our camp to help us, and volunteered to act as timekeeper, turned his back resolutely on the eclipse and saw absolutely nothing of it, because in the preliminary drills he found he had a difficulty in picking up the time again when once he looked away from the face of his chronometer.

This time then we have a relay of timekeepers, one replacing

the other at "sixty seconds more." This signal is given by both. The one who gives the time has his back to the sun, the other will see what he can At my signal, "Go," depending upon the final disappearance of the photosphere as seen in a $3\frac{3}{4}$ with neutral tinted glass, the timekeeper first on duty is to sing out "105 seconds," and give the time every five seconds, "100 seconds," "95 seconds more," and so on.

The question of lamps during the eclipse is settled in the following way. If the sky be quite clear, some will certainly be wanted for the timekeepers in the huts, and for reading the fine graduations of the delicate chemical thermometers which I have brought with me. But if the sky be not clear, then others may be wanted too. So Captain King Hall has arranged to have ten lamps, each in charge of a bluejacket, in reserve, in the middle of the camp, so that anybody who wants one has only to say so to be immediately supplied.

A guard of five marines has remained permanently in the camp during our stay. They are generally dressed in most arctic-looking costumes known as "lammy suits" These are nothing more than a pair of trousers and jacket (with a hood), made out of ship's blankets, worn over the ordinary dress, they were invented, I believe, by the sailors when they made a long stay at Spitzbergen last year. They seemed to be grand clothes for a camp, and in fact one of the marines seems to be seldom out of his—he appears to revel in the warmth it gives. Besides acting as guard to the camp, the marines are useful in many other respects; for instance, in addition to signalling for us, they are very good cooks, and all our cocoa, soups, meat, &c., brought from the ship, only need to be handed over to them to be served up in our tent in a very appetising condition. Since the eclipse begins so early on the morrow, arrangements have been made that a few of us shall sleep in the camp to-night, and thus come under their special care; the ship's company will come over in the morning.

CHAPTER VIII.—AFTER THE ECLIPSE—A LETTER FROM TRONDHJEM.

TRONDHJEM, *August* 14.

SINCE writing my last notes, the eclipse has come and gone, and we are homeward bound, rather depressed, but satisfied that the "Volage" and ourselves had done our duty, and that it was Dame Nature alone who was to blame.

Although on the 8th the weather in the forenoon was very fine and promising, towards the latter part of the day a change set in, and dark clouds came up.

Captain King Hall, who came over from the ship in the afternoon, soon detected what was wrong; there were two currents, an easterly and a westerly one, contending for mastery. This elemental war was watched with anxiety for two or three hours, and at times the weather chances improved, but later rain set in, and we could only hope against hope. It rained during our dinner hour in the tent, an excellent one lent us by the War Department, kept dry under foot by a tarpaulin, and a deep trench outside cut in the peat. Lieutenant Martin, the navigating officer, to whose constant care many of the admirable arrangements on the island were due, who had not only taken charge of the integrator, but who has *ipsissima manu* put up all three of the discs,[1] remained on shore and did the honours.

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[1] A reference to the use of discs will be found on p 10, and one of the results

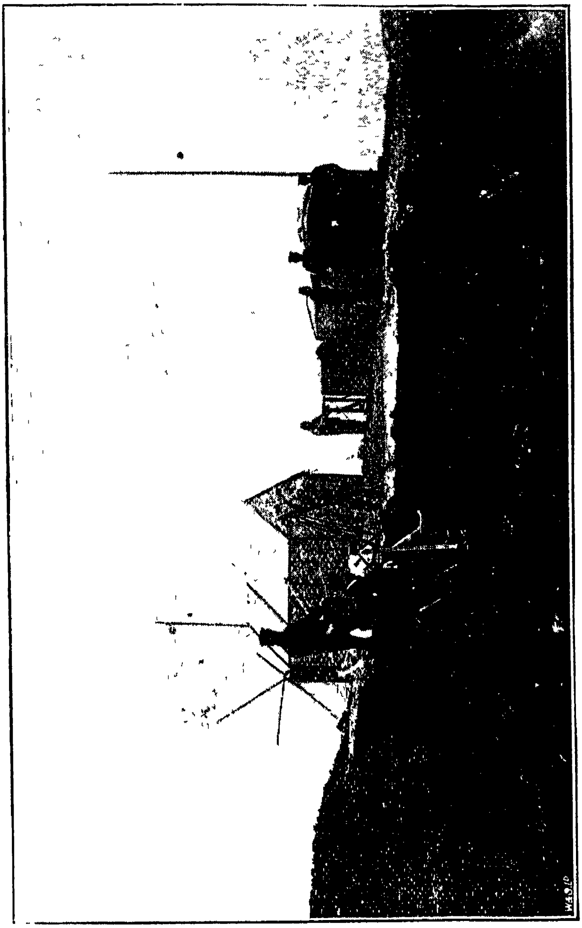

FIG. 25.—Lieut Martin, R.N., setting up a disc.

obtained by their use is stated on p 96. It may be here stated that their value depends upon the eye being absolutely shielded from the light of the lower corona.

It may be worth while to state that the eye-pointers used in connection with the discs were impromptu affairs made by the ship's carpenter, but they promised to work well. There must be fine adjustments, because it is not likely that the point to be occupied by the eye will be calculated to an inch For these adjustments, then, we have first a horizontal bar, on which hangs a vertical piece of wood about ten inches long, free to slide. On this piece of

A dim memory of the Latin grammar suggested champagne as an accompaniment of the well-cooked provender, for were we not bound on the morrow to face not only the *ingens æquor*, but, if all went well, something still more awe-inspiring.

Dinner over, the process of filling up all dark slides with the plates for the morrow was accomplished by Lieutenant Martin, Mr. Fowler, and Dr. Lockyer, after which it was suggested that we should turn in early.

The Rev. E. J. Vaughan, my son, and I occupied one of the army tents, while Mr. Fowler and Lieutenant Martin had their stretchers placed in Kio Town Hall as the 6-inch hut had been called. Our last survey of the weather was not one to raise our spirits to any great extent, but we were still buoyed up by the fact that, as a rule, the early mornings, looking eastward, had been moderately clear.

As we expected the "Garonne," on her return from Spitzbergen, to anchor near our island some time in the early morning, we had arranged with the guard to light a beacon fire directly she was sighted, to show them our whereabouts.

At 1.30 my son took it into his head to take a stroll around outside; his attention was first drawn to the beacon burning brightly on the hill, and the four marines in their lammy suits standing by the side of it. Looming up very black and large, close to our island, was the good ship "Garonne," before her time. It was not long before we received two nocturnal visitors, Captain Harry and Mr. Müller, who had come off to see about the day's arrangements. The weather was anything but pleasant, and their return to the ship was heralded by a downfall of heavy rain.

At 4 A.M. the parties, led by Captain King Hall, began to arrive from the ship, the first thing they did on landing being

wood slides up or down a piece of brass carrying a pointer marking the place of the eye; this is brought into position at the beginning of totality by the amanuensis.

FIG. 27.—The Camp on Kio Island, showing the fjord and the island and land to the eastward.

FIG 28.—The Eclipse Observers. Photograph taken by Mr. Fowler immediately the Eclipse was over.

to make cocoa and have breakfast. Mr. Thomas, in charge of the chronometer, and the readers of the thermometers, were the first to take their stations, and for these at the time of first contact the work began with the sky almost entirely covered with clouds, with narrow breaks near the sun's place, and wider ones near the horizon, a condition of things which relieved Mr. Fowler from his spectroscopic determination of the beginning of the eclipse.

Gradually everybody fell into their stations; the sketchers went up the hill, but there was no need for them to carry out their instructions to shield their eyes by turning their backs to the sun.

There had been no sun to adjust the siderostat, so it was clear that the 9-inch prismatic camera would in all probability not be employed. Still Dr. W. Lockyer stood by at the mirror to make final adjustments.

A few minutes before totality the delicate crescent was seen dimly through one of the breaks. I watched it in the 3¾-inch for a minute or two, but the clouds closed up before the commencement. I gave it a little time, and then gave the signal, "Go," in order especially to start the 6-inch prismatic camera, as the important ten-seconds-before-totality signal could not be given in the way agreed upon. All the photographic work, with the exception of the 9-inch, then went on as if the eclipsed sun were visible. The actual commencement of totality occurred shortly afterwards, the swoop of the shadow being almost felt. This instant was noted by Mr. Thomas amid a cry for lamps, especially from the time-keepers and some of the observers in the huts.

The time of the end of the eclipsed eclipse was also noted by Mr. Thomas, and the affair was over for most of us, although the colour observers and the meteorologists continued their notes till the fourth contact.

And then an unexpected thing happened. Captain King Hall called his men together, and, in a few admirably chosen words, expressed to me the regret of the "Volage" that such an important attempt to advance knowledge had been frustrated. In reply, I told him that I thought an almost more important thing than the observation of a single eclipse had been accomplished. He had demonstrated that with the minimum of help, and that chiefly in the matter of instruments, such a skilled and enthusiastic ship's company as his could be formed in a week into one of the most tremendous engines of astronomical research that the world has ever seen; so that if the elements had been kind, all previous records of work at one station would have been beaten.

I added that I felt sure that the leaders of British science would thank him, his officers and men, for what they had done in aid of science when it came to be known, and further, that the kindness which the eclipse party had received on board the "Volage" had inspired a gratitude which it was not easy to express in words.

The party subsequently fell in to be photographed by Lord Graham and Mr. Fowler; then away to the ship for breakfast, and a curtailed Church service.

The repacking of the instruments was begun after breakfast, as the "Volage" was to rejoin the squadron the next day. Under these circumstances the Town Hall was left standing for the benefit of the friendly Lapps whose island we had invaded, but who seemed rather to enjoy our doings than otherwise. Talking of the Lapps, it would be interesting to know the Lapp mythology and folk-lore concerning eclipses. Immediately after totality, or rather so soon as it was light enough to render the channel separating Kio from the island to the eastward clearly visible, we saw a large boat full of Lapps firing a *feu de joie*. The fact may be chronicled. I was all the more struck by it, as it seemed to be possibly connected with

the Eastern custom to light fires to frighten away Rahoo, whose swallowing of the sun causes the eclipse.

It seemed quite certain that the parties at Vadso had fared no better than ourselves, and this was confirmed by the news brought by the "Calypso's" steam cutter in the afternoon. This cutter subsequently conveyed my son and myself to the "Garonne," meeting her about a mile outside Kiö, and while the island was being rapidly left astern, full particulars were told me of all the camps which many of my shipmates on the "Garonne" had visited after the eclipse.

It was at Hammerfest that we first had news of any success and that at Bodo. I had heard that there was a strong party of German astronomers at this place, but one of the fortunate ones, who subsequently came on board, told me, to my great regret, that there were no fixed instruments there at all, and that the photographs of the corona were taken with a small camera of the ordinary make.

CHAPTER IX.—THE NOVAYA ZEMLYA RESULTS.

It is not to be wondered at that great disappointment was felt, and expressed, by the Norwegian parties at the total failure of all their efforts. Next came the news of total failure also in Japan. There was, however, some consolation in store. Those observers who had proceeded to the most inhospitable regions had fared the best. It was generally known that one of the Russian expeditions had been despatched to Novaya Zemlya.

After the instruments had been dispatched to Lapland in H.M.S. "Volage," Sir George Baden-Powell, with admirable public spirit, offered to take a British expedition to Novaya Zemlya in his yacht "Otaria," if observers and instruments were forthcoming He consulted me on the subject, and ultimately, with the authority of the Vice-President of the Council, Mr. Shackleton, one of the computers employed by the Solar Physics Committee, was detailed to form part of the expedition.

I naturally could not supply him with as powerful instruments as those taken to Lapland, but in spite of this Dame Nature allowed a grand success to be scored at Novaya Zemlya, which would not have had a British observer within hundreds of miles had it not been for the chapter of accidents and the public spirit of Sir George Baden-Powell.

It was evident, therefore, that in inflicting upon us at Kiö

so great a disappointment, Nature was not really cruel, but was pointing a moral, namely, that in attempting to obtain records of eclipses, no effort should be spared in occupying every coign of vantage, however inconvenient to get at or unpromising as regards weather conditions.

The "Otaria," after touching at Vardo, sailed for Novaya Zemlya, making for the Samoyede settlement of Karmakul, in the southern island. The intention was, after meeting some Russian astronomers, and obtaining information as to the navigation, to take up a point of observation some ten miles further south, in Gooseland, on the central line of the shadow-path. Although the party had not a very good chart—no trustworthy ones of these remote regions being published—they got into the bay on Bank Holiday Monday (August 3), and were going at a good speed—about ten knots—when the vessel gave three bounds and stood still, heeling over on her side.

The account of this *contretemps*, communicated by Mr. Shackleton to the *Yorkshire Daily Post* continues:—

"Everybody hung on to something, for it was impossible to stand. Fortunately, however, the reef was only of soft rock, and it did little damage to the ship; only for four days we remained like that, about a mile away from the nearest land. We could not walk except by holding on to ropes, and had to get our meals on our knees or on the deck with cushions. After four days' work the sailors nearly emptied her, and pumped out all the drinking-water, and then at high tide pulled her off."

"The mishap arose from a little want of familiarity with the Russian cartography of these parts, which is naturally better than ours. It turned out that the soundings of the deeper portions were, so to say, in fathoms and the shallower in feet. A few of the deeper soundings having been verified by the lead, the rest were taken for granted, with the unpleasant result already detailed.

In spite of this mishap, everybody working with a will, things were more or less ship-shape on the eclipse morning. There had not been many opportunities of adjustment, but, not unmindful of possibilities, I had taken the precaution of having every

portion of the more important instruments adjusted, and each adjustment plainly marked before I sent it off.

I deal first with the prismatic camera

The instrument available was that which had been used in Brazil during the solar eclipse of 1893. The object glass is a

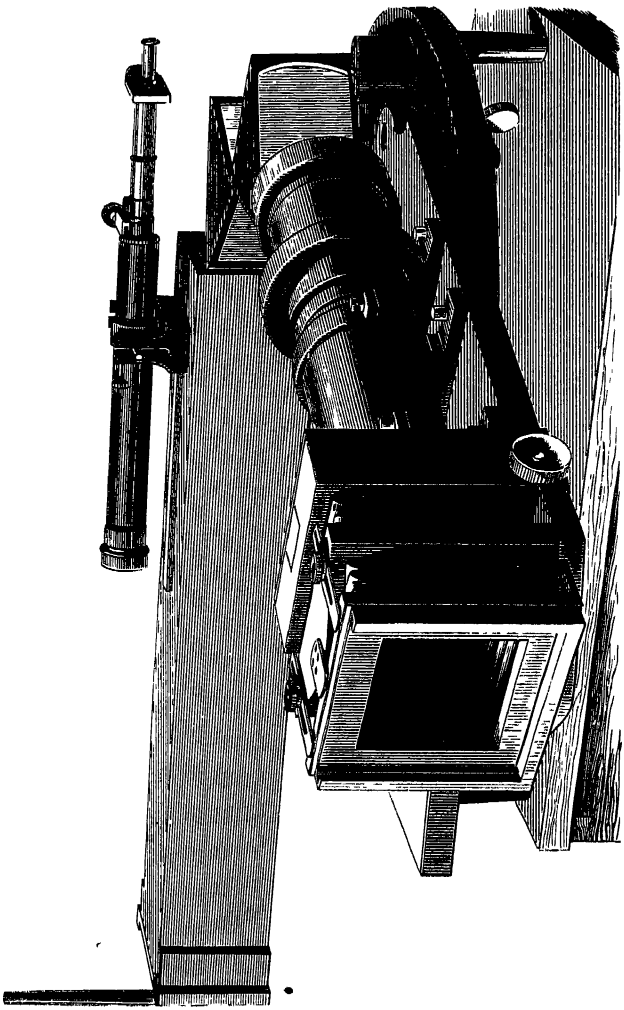

FIG 29.—The prismatic camera used in Novaya Zemlya

Dallmeyer doublet of 19 inches equivalent focal length, with an aperture of 3·25 inches; the image of the inner corona, therefore, is a ring of 0·2 inch diameter. Two prisms of 3 inches clear aperture were used, with their refracting edges perpendicular to the horizontal, each having a refractive angle of 60°; the light was reflected into the apparatus by a siderostat. The length of the spectrum given by this combination was 1·5 inches, from F to K, or 2·3 inches, from D^3 to K. A siderostat is an instrument designed by Foucault, in which a mirror is used which reflects light into a horizontal telescope placed to the south of it. The motion of the mirror is so regulated that the light is continuously reflected into the telescope the whole time the light-giving body remains above the horizon. Its use replaces the equatorial mounting and motion of a telescope.

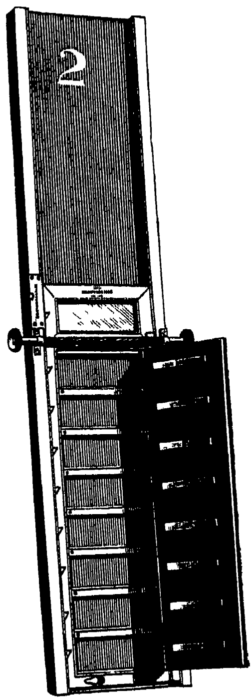

FIG. 30.—The dark slides.

In 1893, the photographs obtained by this instrument in Brazil were not in focus in the ultra-violet, in consequence of the difficulties of adjustment under eclipse conditions. The precaution was taken, therefore, of making all the necessary adjustments by obtaining some stellar photographs with the instrument before it left England. Ultimately, a photograph of α Lyræ left nothing to be desired, and the then positions of all the parts were carefully marked.

Three specially constructed dark slides, carrying eight plates each ($4\frac{1}{4} \times 1\frac{5}{8}$ inches), were employed, the change from plate to plate being effected by means of a rack and pinion

attached to the dark slides. The plates used were Edwards' isochromatic.

A table based on data furnished by the results of the 1893 eclipse was drawn up for use on the central line in Novaya Zemlya, showing times and duration of exposures of the twenty-four plates it was hoped to obtain.

Unfortunately, however, the expedition found it impossible to reach the central line. The duration of totality at the site occupied was shortened by 25 seconds. Mr. Shackleton therefore made the necessary alterations.

The exposures were made by means of a card moved by hand in front of the prisms, and when this was done as quickly as possible the exposure was reckoned as instantaneous. Mr. Shackleton obtained twenty-one photographs with the prismatic camera, thirteen during totality.

As the final reduction of the photographs will take some considerable time, I thought it of importance to send to the Royal Society at once, for the benefit of other workers, reproductions of two of the best photographs obtained. These have just been published, and I have received permission to give them here (see Figs. 31—33).

The first was taken instantaneously at the beginning of totality. The principal arcs are those of hydrogen and the H and K lines seen in the spectrum of calcium; these long arcs, together with the numerous short ones, represent the spectrum of the sun's limb at the moment of totality, Mr. Shackleton determining the exact instant by watching the disappearance of the bright continuous spectrum with the aid of a small direct-vision slitless spectroscope. This plate may undoubtedly be said to have been exposed within 0·5 second after the commencement of totality; it had an instantaneous exposure, and this was sufficient to give a record of the spectrum from D^3 to H_μ in the ultra-violet.

The second was exposed for a period of forty seconds, beginning

at thirty-nine seconds from the commencement of totality, so that it records the spectrum near mid totality. The two over-

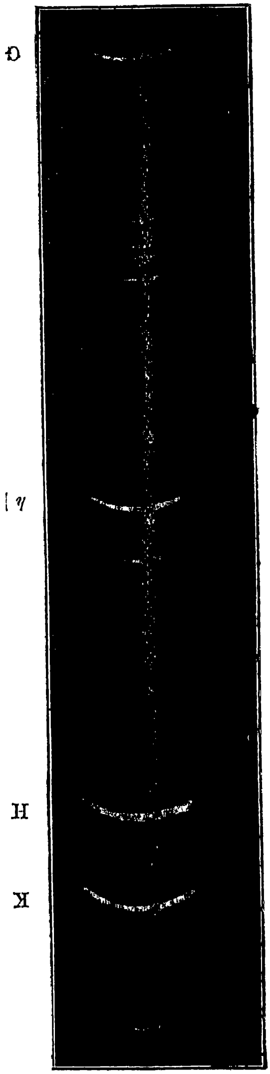

FIG 31 —Spectrum of chromosphere obtained during the total eclipse of 1896, showing lines photographed between K and G

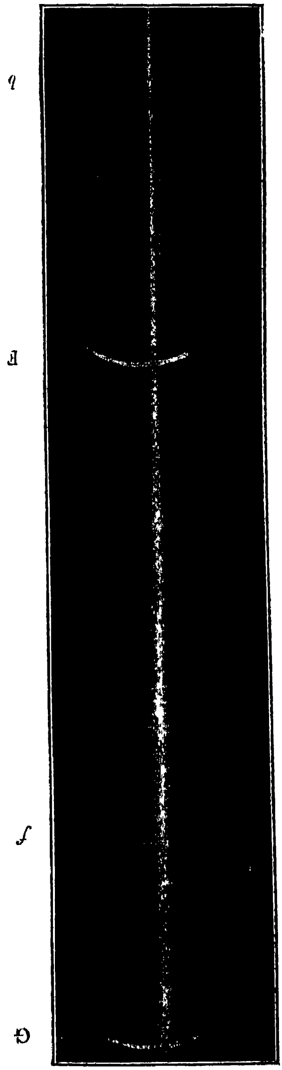

FIG. 32.—Spectrum of chromosphere obtained during the total eclipse of 1896, showing lines photographed between G and *b*.

lapping disconnected rings to the left are the images of the prominences round the sun's limb represented in the H and K

light, the other discontinuous rings to the right are the images in H_δ, H_γ H_β radiations respectively, the ring further to the right, which is of more continuous structure than the others, is the 1474 K ring of the corona spectrum

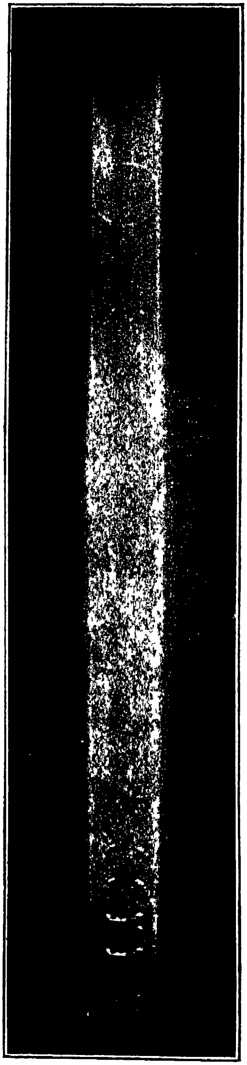

FIG 33 —The 1474 light ring compared with the prominence rings as depicted in H and K light.

It is seen at a glance that while the greatest intensities of the H and K light occupy the same positions, the *loci* of greatest intensity in the case of the 1474 light are widely different.

There are other fainter rings both of the prominences and the corona, which are well seen on the original negative, but it is too much to hope that these will be seen in the plate, being lost in the process of reproduction.

An enlargement of the 1474 K ring compared with an oriented photograph of the lower corona will be dealt with subsequently (p 113) It will be seen that the prismatic camera has picked out the brightest parts of the corona, and where it is strongest the spectrum ring and the continuous spectrum at those points is most intense, whilst a prominence occurring at any point of the sun's limb does not alter the intensity of the ring at the corresponding part.

A preliminary comparison of the results obtained in 1893 and 1896 has shown many points of difference; it also indicates that the photograph so happily secured by Mr. Shackleton, and the cusp photograph taken by Mr Fowler, in 1893, both represent the spectrum of the chromosphere.

Except in the case of the lines visible in the spectra of hydrogen, helium, and the longest lines in the spectra of some of the metallic elements, notably calcium and strontium, there is little or no relation between the intensities of the lines visible in the chromosphere and Fraunhofer spectrum.

There is, then, already evidence that the photographs which we owe to the public spirit of Sir George Baden-Powell and the energy and skill displayed by Mr. Shackleton, will considerably widen our knowledge of solar physics and chemistry.

It is not too much to say that "the winter of our discontent" at Kio was turned to "glorious summer" by the sun of Novaya Zemlya!

But these spectrum photographs, important as they are, do not represent all the results obtained in Novaya Zemlya, or even by Sir George Baden-Powell's party. I had been able to send out a 4-inch telescope to Novaya Zemlya with the object of securing photographs of the corona, and this part of the work was also successful, but as the results are not yet published, for our knowledge of the form put on by the corona in 1896 we are so far dependent upon the communication made to *Nature* by Baron Kaulbars, touching the pictures obtained in Finland,[1] and the important collection of memoirs communicated to the Imperial Academy of Sciences of St. Petersburg, brought together in a volume of 144 pages recently published, giving an account of the work in Novaya Zemlya and on the Amur. The volume contains some admirable reproductions of the photo-

[1] *Nature*, vol. lv, p. 293.

graphs taken by MM. Kostinsky and Hansky at Malya Karmakouly in Novaya Zemlya. A copy of M. Kostinsky's second photograph exposed during 10 seconds is given here.

In a drawing MM. Kostinsky and Hansky have brought together all the details they have been able to trace on their

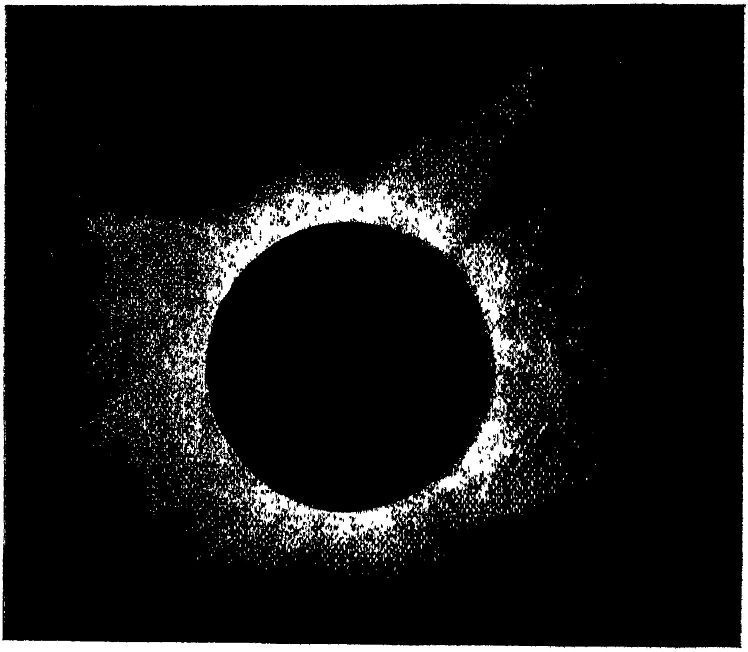

FIG. 34.—The Corona of 1896, Kostinsky

negatives (see Fig. 35), as well as the positions of all the prominences observed (these are shown in black for greater clearness).

It is certainly very fortunate that these photographs of the corona, together with those still unpublished obtained by Sir George Baden-Powell, were secured, since they support statements made now many years ago touching the change of form of

the corona, as well as its spectrum, in relation to the sun-spot period.

Observations of the sun without the intervention of an eclipse have shown that there is an enormous change in the

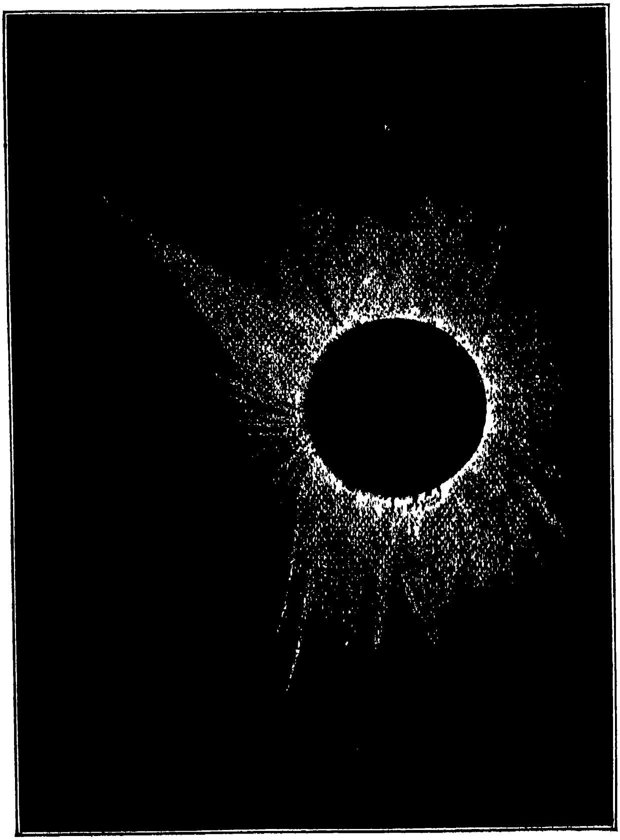

FIG 35.—Drawing bringing together all the details shown on Kostinsky's and Hansky's photographs. (Prominences shown in black.)

solar activity every eleven years, both in the spots and prominences, and that these changes depend upon the waxing and waning of atmospheric disturbance.

If we take the period of greatest tranquility as the beginning of the cycle, we detect no disturbed spots or prominences. These begin concurrently in about lat 30° N. and S.

In about three and a half years the maximum of disturbance is reached in about lat. 16°. After this the action gets less and less during seven and a half years until it disappears in about lat. 5°, when another disturbance begins in lat 30°. We may

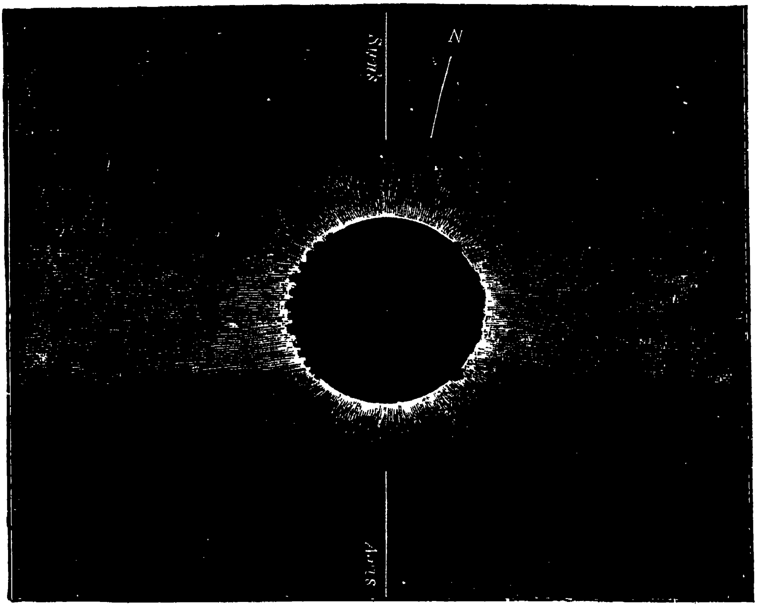

FIG. 36.—The Corona of 1867.

say broadly that the history of solar weather consists in the changes brought about in the sun's atmosphere by the progress of disturbances beginning in high latitudes and ending near the equator, each disturbance taking about eleven years to run through its phases, the period of greatest intensity occurring at about three and a half years from its commencement.

Eclipse work since 1878 has shown that the corona, as well as the spots and prominences, is involved in the disturbance, as is clearly indicated by its change of form and variation in brilliancy, to which I now proceed to refer.

If we take the simplest case first, that of minimum sun-spots depending upon minimum solar activity, we then get chiefly an equatorial elongation of the corona with a marked absence of irregular streamers in mid-latitudes. In support of this statement, I append two drawings made at the eclipses which took

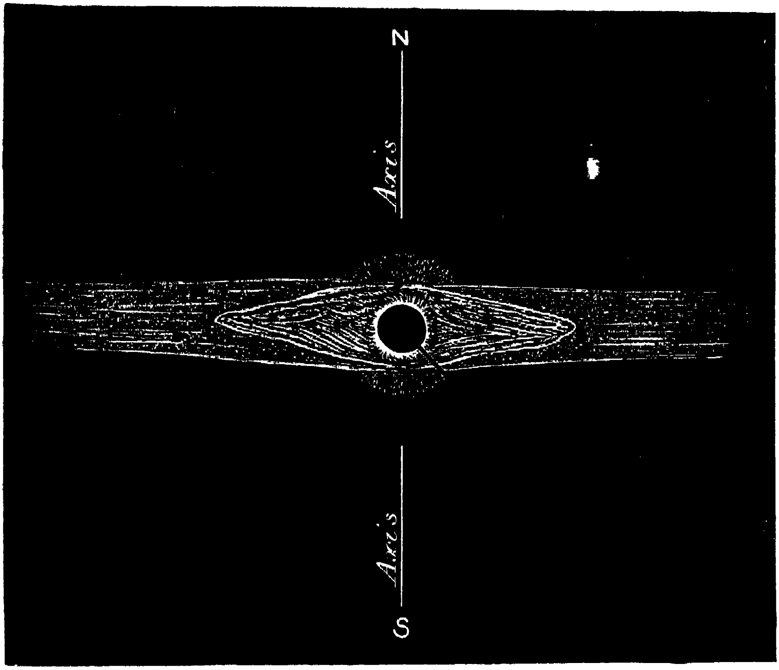

FIG. 37.—The Corona of 1878, as observed by Newcomb by means of a disc.

place in the years 1867 and 1878, years of sun-spot minimum. In the second drawing, made by Professor Newcomb, the disc is shown by which he eclipsed the brighter lower reaches of the corona, so as to give his eye the best chance of seeing feeble extensions. The pole supporting the disc was vertical, but it is shown slantwise in the illustration, because it is most important to show the sun's axis upright.

At the minimum period not only are these extensions best seen, but the exquisite structure near the sun's poles is very strikingly revealed.

At and near the maximum period all is changed,[1] and we get streamers and their separating rifts very irregularly distributed In 1896 these irregular streamers formed striking objects, and we know from the sun-spot observations that the atmosphere was more than usually disturbed—more than might have been anticipated, seeing that the maximum was due to occur in 1892.

The valuable collection of memoirs, to which I have already referred, contains an important contribution on this subject, also from M. Hansky[2] He gives a reproduction of several coronas, showing that the form varies with the sun-spot curve. I am glad to find that his studies entirely confirm all I have written on this subject during the last nineteen years.

It is obvious then that the photographs of the corona, though they are of much lower value from the theoretical point of view than the spectrum photographs, will be very useful for the further study of the change in the appearances of the corona from eclipse to eclipse in relation to the sun-spot period.

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[1] See my *Chemistry of the Sun*, 1887, p. 436 *et seq.*

[2] "Ueber die Corona und den Zusammenhang zwischen ihrer Gestaltung und anderen Erscheinungsformen der Sonnenthatigkeit."

CHAPTER X.—THE CHEMISTRY OF THE SUN AS DETERMINED IN 1893 AND 1896.

ALTHOUGH it will take some time to make a complete study of the spectrum photographs obtained during the eclipses of 1893 and 1896, because much experimental and observational laboratory work is involved, it has been rendered evident by what has been done so far that results of great importance have been secured.

We have known since 1865 that the spectrum obtained when certain parts of the sun are examined is not the same as that with which we are most familiar. In that year the first proof showed that certain Fraunhofer lines, and not all, are widened in the spectrum of a sun spot. The second, dating from 1868, showed that certain and not all Fraunhofer lines are brightened in the spectrum of a prominence or of the chromosphere.

In attempting to explain these differences we are brought face to face with some of the most difficult parts of solar theory.

In the first place we should expect that if the vapours in the spots on the one hand, and in the prominences and chromosphere on the other were identical, the lines seen dark and widened in one and brightest and most prominent in the other, would be the same.

Secondly, if these vapours were those which produced the Fraunhofer lines there should be no difference between the ordinary spectrum, the spot spectrum, and the prominence and chromosphere spectrum.

This seems clear enough. The fact is there is an enormous difference between the three spectra I have named.

Kirchhoff, who was the first to consider these questions, placed the absorbing atmosphere, which gives birth to the dark lines in the spectrum, at a considerable height above the photosphere.

As a result of solar spectroscopic observations, combined with laboratory work, Dr. Frankland and myself came to the conclusion, in 1869, that at least in this particular, Kirchhoff's theory of the solar constitution required modification. In that year we wrote as follows :[1]—

"May not these facts indicate that the absorption, to which the reversal of the spectrum and the Fraunhofer lines are due, takes place in the photosphere itself or extremely near to it, instead of in an extensive outer absorbing atmosphere?"

In an early observation of a prominence on April 17, 1870, I found hundreds of the Fraunhofer lines bright at the base, and remarked that a "more convincing proof of the theory of the solar constitution put forward by Dr. Frankland and myself could scarcely have been furnished."[2]

During the eclipse of 1870, at the moment of disappearance of the sun, a similar reversal of lines was noticed; we had, to quote Professor Young, "a sudden reversal into brightness and colour of the countless dark lines of the spectrum at the commencement of totality." On these observations was based the view that there was a region some two seconds high above the photosphere, which reversed for us *all* the lines visible in the solar spectrum; and on this ground the name "reversing layer" was given to it.

Continued observations, however, led me, in 1873, to abandon the view that the absorption phenomena of the solar spectrum are

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[1] *Proc. Roy Soc.*, vol. xvii, p. 88.
[2] *Ibid*, vol. xviii, p. 358

produced by any such thin stratum, and convinced me that the absorption took place at various levels above the photosphere. I need not give the evidence here; it is set forth in my *Chemistry of the Sun* (chap. xxii, pp. 303–309). On the latter hypothesis the different vapours exist normally at different distances above the photosphere, according to their powers of resisting the dissociating effects of heat."[1]

My observations during the eclipse of 1882, in the seven minutes preceding totality, to my mind set the matter at rest.

"We begin with one short and brilliant line constantly seen in prominences, never seen in spots. Next another line appears, also constantly seen in prominences; and now, for the first time, a *longer* and thinner line appears, occasionally noted as widened in spots; while, last of all, we get, very long, very delicate relatively, two lines constantly seen widened in spots, and another line, not seen in the spark, and never yet recorded as widened in spots."[2]

Similar observations in the same part of the spectrum were made by Professor Turner in 1886.[3] His observations were made under less favourable conditions than those in Egypt, and in the absence of statements as to the relative lengths of the lines observed, it is impossible to utilise them fully.

This is one of the most important points in solar physics, but there is not yet a consensus of opinion upon it. Professor Young and others apparently still hold to the view first announced by Dr. Frankland and myself in the infancy of the observations, that the Fraunhofer absorption takes place in a thin stratum, lying close to the photosphere.

It was to tackle this point afresh that the spectrum observations of 1893 and 1896 were designed. In my paper on the 1893 results I discussed the numerous photographs obtained during the eclipse, and I gave maps showing that there was only the slightest relation between the intensities of the lines

[1] *Proc. Roy. Soc.*, vol. xxxiv, p. 292.
[2] *Ibid.*, vol. xxxiv, p. 297.
[3] *Phil. Trans.*, 1889, vol. clxxx, A, p. 391.

common to the Fraunhofer and the eclipse spectrum, and, further, that only a few of the Fraunhofer lines are represented at all. Not only this, but in the eclipse photographs there are many bright lines not represented at all among the Fraunhofer ines.

I give copies of these maps here. In them we have compared the ordinary spectrum of the sun between wave-lengths 4100 and 4300, copied from Rowland's map, compared with the bright lines photographed during the eclipse (Fig. 38).

The eclipse of 1893 therefore told us with no uncertain sound that the chromosphere is certainly not the origin of the Fraunhofer lines, either as regards intensity or number.

At this point it will be convenient to introduce a short historical statement showing how this result is in entire harmony with all prior work.

From the eye observations made since 1868, I pointed out many years ago that there is evidence that the quiescent chromosphere spectrum indicates a higher temperature than that at which much of the most valid absorption takes place; in other words, that the majority of the lines associated with lower temperature are produced above the level of the chromosphere.

The conclusion with regard to the high temperature of the quiescent chromosphere depended chiefly upon the Italian observations and upon investigations communicated by myself to the Royal Society in 1879[1] and 1881[2] on the effect of high-tension electricity on the line spectra of metals (Fig. 39).

These investigations consisted in noting (1) the lines brightened on passing a spark in a flame charged with metallic vapours, and (2) the lines brightened on passing from the arc to the spark. It was found, in the case of iron, that two lines in the visible spectrum at 4924·1 and 5018·6, on Rowland's scale, were greatly enhanced in brightness with higher temperatures, and

[1] *Proc Roy. Soc*, 1879, vol. xxx, p 22.
[2] *Ibid.*, 1881, vol. xxxii, p 204.

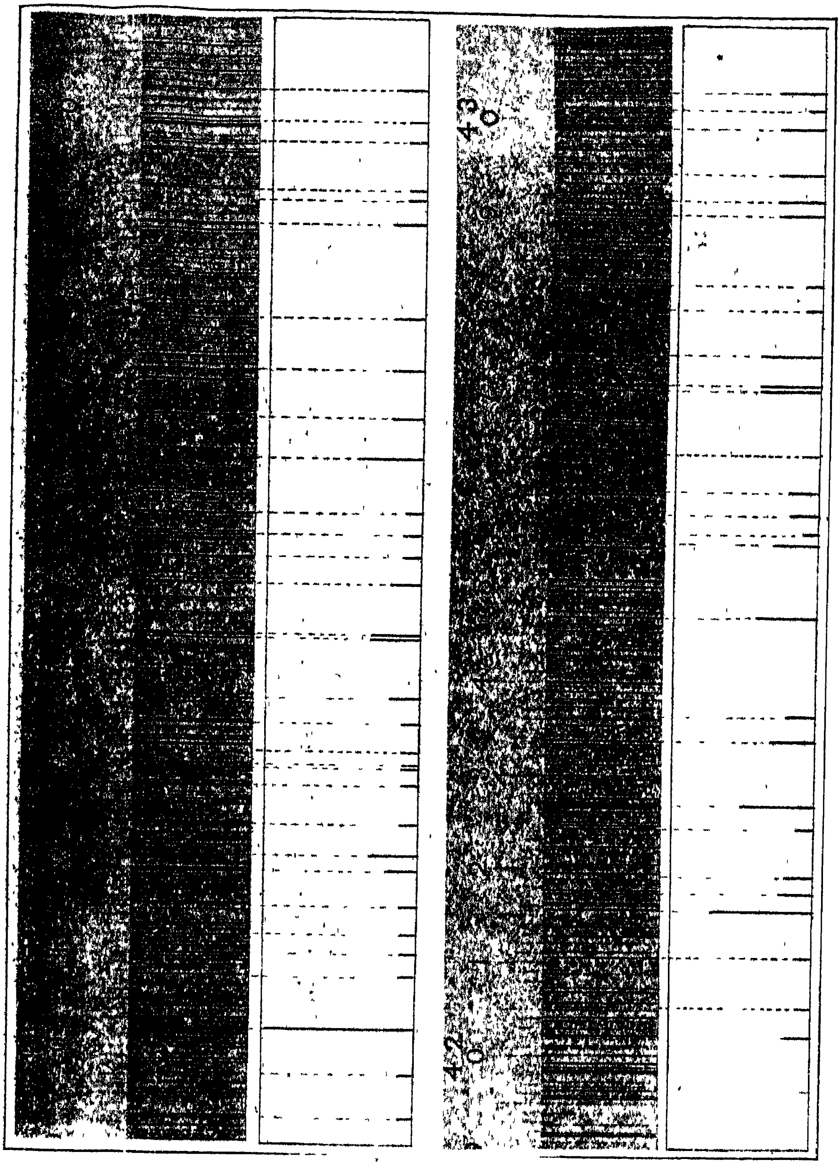


FIG 38.—Comparison of Fraunhofer lines with the chromospheric lines photographed during the eclipse of 1893.

were very important in solar phenomena. Thus, the line at 4924·1 was at times the only representative of iron in the chromosphere; upwards of 1000 lines in the visible spectrum of iron gave no sign.

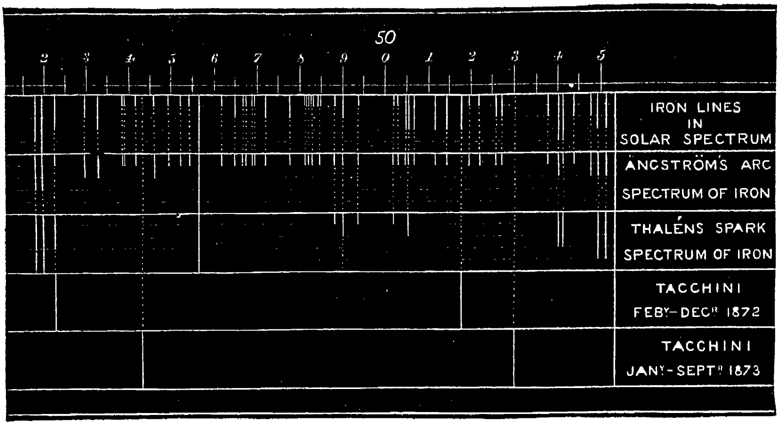


FIG. 39.—Tacchini's observations of the iron lines at 4924·1 and 5018·6 in the spectrum of the quiet chromosphere in 1872. It will be observed that new prominence lines were recorded when the iron lines disappeared later.

Spots are conceded to be cooler phenomena than those observed in other parts of the photosphere, so we should not expect to find the hotter lines so frequent in them. Fig. 40 gives the facts. It is a comparison of the iron lines observed in spots and in the quiet chromosphere during the same time in 1872, the spots being observed at Kensington, and the chromosphere at Palermo. It will be seen that none of the lines seen in the chromosphere were seen in the spots, and *vice versâ*.[1]

It was natural to suppose that the iron vapour producing the cooler lines was higher up than that responsible for the enhanced line at 4924·1. Hence a crucial observation was

[1] The iron line at 4924·1 is seen in the prominences only, the two adjacent iron lines in the spots only. Both "arc" and "spark" lines are shown. The former are produced by passing a *voltaic* current between iron poles, the latter by passing a current from an induction coil with condensers.

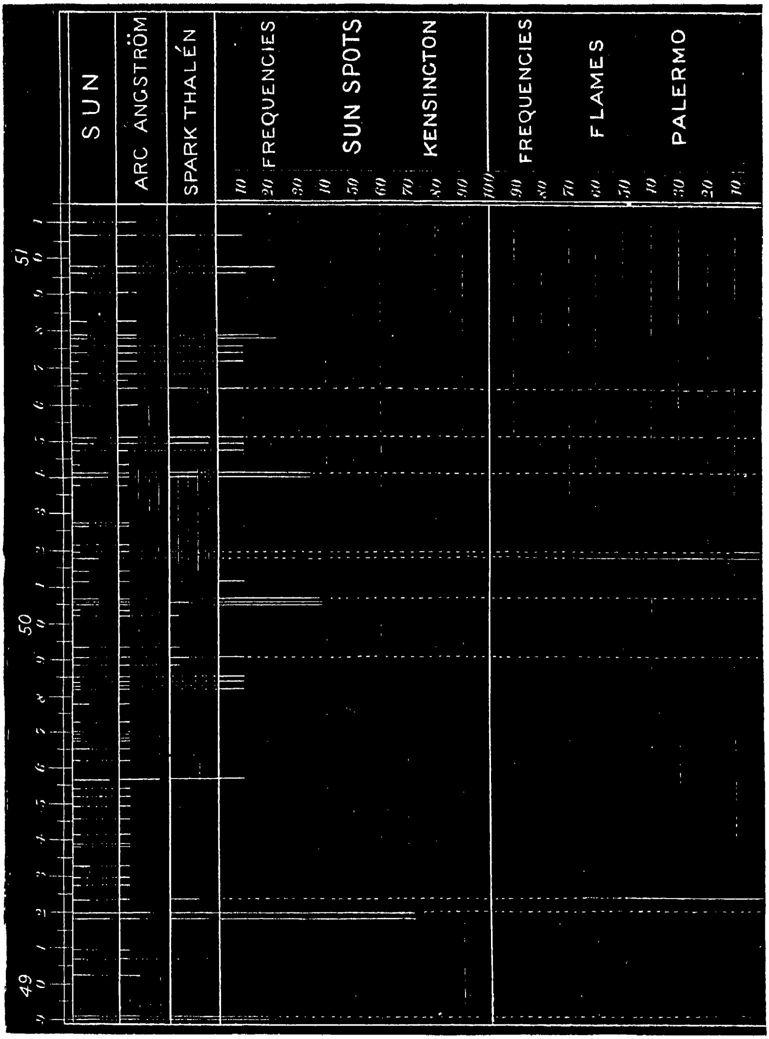


FIG. 40.—Iron spot lines seen at Kensington confronted with iron prominence lines seen at Palermo.

planned for the eclipse of 1882. If the vapour were higher it should be dimmer, and its lines should, if seen at all, be seen long and faint very near the beginning of totality, while the

hotter line, being produced by vapours relatively low and at a higher temperature, should be seen short and bright some time before the beginning of totality. Fig. 41 will show how absolutely the prediction was verified by the event.

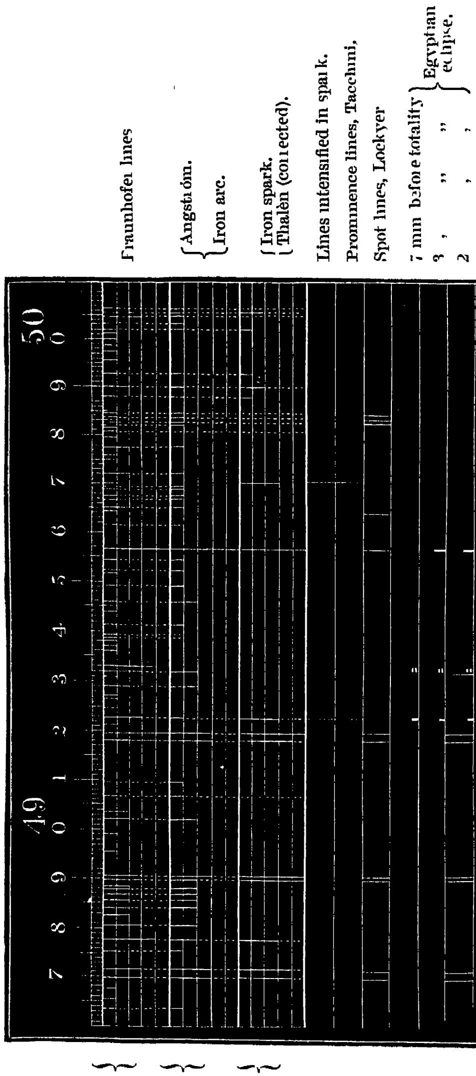


FIG. 41.—The line seen during the solar eclipse in 1882, showing that the prominence line at 4924·1 was seen short and bright seven minutes before totality, and some of the spot lines were not seen till two minutes before totality, and then they were observed long and dim.

It was in order to try to understand such facts as these, facts observed carefully in all their detail, month after month and year after year, that much of my early experimental work was undertaken. By 1872 the influence of quantity or density had been made out; when experiments were made at one temperature the spectrum got simpler as the quantity was reduced, so that the spectrum was finally reduced to its longest line[1] I am glad to see that Sir William Huggins, who appears to be ignorant of my quarter-of-a-century-old work, has quite recently arrived independently at the same conclusion.

Next came the influence of temperature. This was a much more difficult problem to tackle; but finally the association of certain lines with certain temperatures was accepted by everybody, though *why* these changes take place there were and are contending schools of opinion

I next come to the more recent experimental work, which was primarily undertaken in connection with certain stellar problems raised by the photographs of stellar spectra I have now been taking for some years. In this research I have used a much more powerful current and larger jar-surface than that I formerly employed; and, for the reason stated, the records deal with the photographic region.

The importance of these new records, not only in regard to stellar but also to solar physics, it would be difficult to overestimate.

I have already pointed out that in the case of iron in the visible region, the brilliancy of two lines at 4924·1 and 5018 6 was considerably enhanced on passing from the arc to the spark. In the photographic region seven lines follow suit.

These, as well as the two previously observed, are shown in the following table, which also indicates the behaviour of the lines under different conditions, as observed by Kayser and

[1] *Phil. Trans*, 1873, pp. 253 and 639

Runge (K. and R.) and myself (L.) in the arc, and by Thalèn (T.) and myself in sparks:—

LINES OF IRON WHICH ARE ENHANCED IN THE SPARK.

Wave-length.	Intensity in flame.	Intensity in arc (K. and R.) Max. = 10.	Length in arc (L) Max. = 10.	Intensity in spark (T) Max. = 10	Intensity in hot spark (L). Max. = 10
4233·3	—	1	—	—	4
4508·5	—	1	—	—	4
4515·5	—	1	—	—	4
4520·4	—	1	—	—	2
4522·8	—	1	3	—	4
4549 6	—	4	5	—	6
4584·0	—	2	4	—	7
4924·1	—	1	3	6	6
5018·6	—	4	—	—	6

Combining this with former results, we seem justified in concluding that, in a space heated to the temperature of the hottest spark and shielded from a lower temperature, these lines would constitute the spectrum of iron.

It is worth while to turn for a moment to stellar spectra and note in them the behaviour of these lines of iron which are found to brighten as the temperature is increased and which play such an important part in the chromosphere spectrum; if only for the reason that the change in the iron spectrum at different temperatures is really better and more easily seen in stellar than in solar spectra. It is fortunate that in the case of the stars their relative temperatures are defined according to a well recognised law by the relative lengths of the spectra in the ultra-violet; taught by this law we can take the star with the longest spectrum in the ultra-violet as the hottest, from this condition the shortening of the spectrum indicates decreasing temperatures.

In the stars then of which the relative temperatures are

defined in this way, we can watch the behaviour of the iron lines so as to still deal with the example we have so far taken.

What then do we find?

In the hottest stars we find no spectroscopic trace of iron at all. In the stars of medium temperature iron is practically represented by the enhanced lines alone; those which build up, for the most part, the arc spectrum are almost or entirely absent in these stars, while in the cooler ones the arc spectrum is fully represented, and the enhanced lines are entirely wanting.

The intensities of the enhanced lines in some of the hotter stars are shown in the appended diagram, and for the sake of comparison, the behaviour of a group of three lines which are among the most marked at lower temperatures is also indicated. In addition, the diagram shows the inversion in intensities of the spark and arc lines in the spectrum of a relatively cool star such as *α* Orionis.

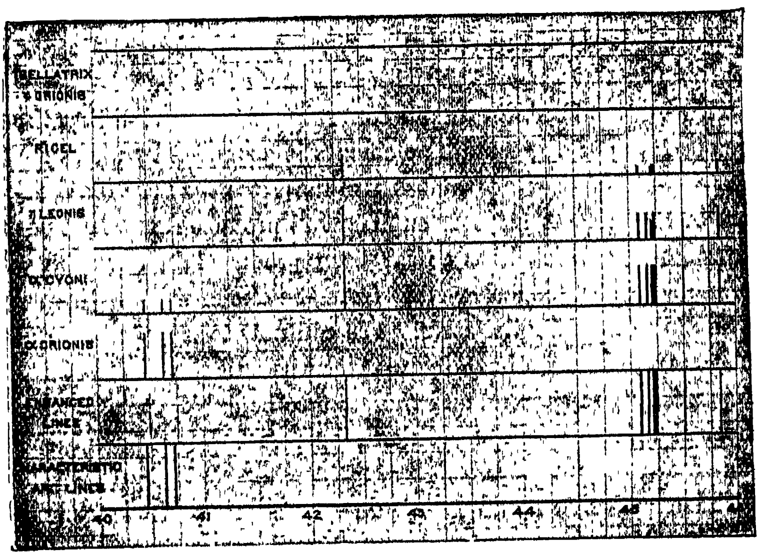


FIG 42.—The enhanced lines of iron and their appearance in stellar spectra.

The facts illustrated by the diagram indicate that the enhanced lines may be absent from the spectrum of a star, either on account of too low or too high a temperature. In the case of low temperature, as I have said, iron is represented by the arc lines, but at the highest temperature all visible indications of its presence seem to have vanished.

To show how very definite this result is, I append three untouched photographs of the stars α Orionis, γ Cygni, and α Cygni, calling attention especially to the behaviour of the quartet of the iron enhanced lines shown below them.

We may say broadly that the stars Bellatrix, α Cygni, and Arcturus, the temperature of which is not widely different from that of α Orionis, represent three very different stages of star life from the point of view we are considering.

In Bellatrix the metallic lines, both enhanced and cool, are almost entirely absent. In α Cygni we get the enhanced metallic lines alone; in Arcturus they are generally absent. I have been careful to mention Arcturus because the statement made in regard to it must also be true for the sun, the spectrum of which is almost identical with that of Arcturus.

This result affords a valuable confirmation of my view that the arc spectrum of the metallic elements is produced by molecules of different complexities, and it also indicates that the temperature of the hottest stars is sufficient to produce simplifications beyond those which have so far been produced in our laboratories; but that is another story from the one now occupying us.

So much then for the stars. We can now take up again the solar story, since we have found Arcturus and the sun to have almost identical spectra, and therefore to be subject to the same physical and chemical conditions, and to exist at about the same mean temperature.

The examination of the eclipse photographs of 1893 and 1896 has already shown that among the bright lines recorded the enhanced lines hold a most important position.

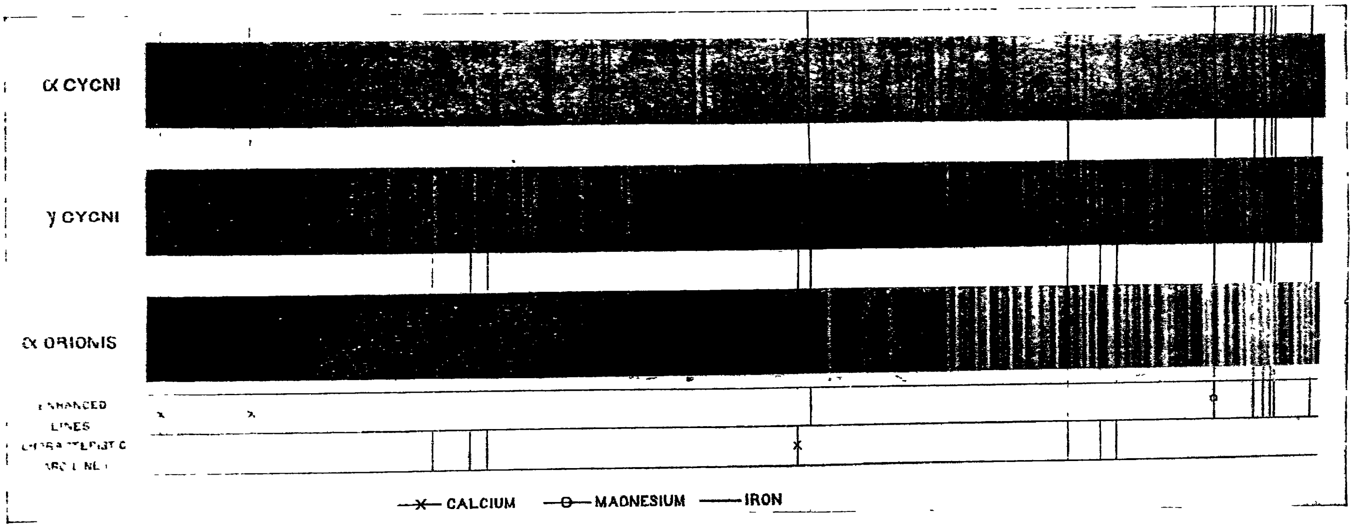


FIG. 43.—Showing that the triplets of the arc spectrum of iron are present in α Orionis and γ Cygni and absent from α Cygni, and that the quartet of enhanced iron lines is present in α Cygni and absent from γ Cygni and α Orionis.

In the case of iron, the enhanced lines were all present in the chromosphere during the eclipse of 1896, and most of them in that of 1893, their intensities being greater than those of the corresponding Fraunhofer lines. Many of the characteristic arc lines of iron also appear in the chromosphere, but the presence of the enhanced lines with such great intensities indicates that at least in some parts of the chromosphere the temperature of the iron vapour is considerably higher than that of the iron vapour which is most effective in producing the Fraunhofer lines. A similar result is obtained when other substances are considered. The special importance of the enhanced lines in the chromosphere is shown by the following figures relating to substances which have been most completely studied :—

No. of enhanced lines of iron, magnesium, calcium, manganese, nickel, titanium, so far tabulated in the region F to K	63
No. of these lines photographed in eclipse of 1893 in the same region	28
Percentage of enhanced lines of iron, &c., in eclipse of 1893	44 per cent.
No. of enhanced lines photographed in eclipse of 1896	41
Percentage of enhanced lines of iron, &c., in eclipse of 1896	65 per cent.

These numbers show that the chromospheric spectrum is largely composed of enhanced metallic lines in addition to the lines of hydrogen and helium.

In the Fraunhofer spectrum enhanced lines may be regarded as wanting, for in the case of iron and magnesium, at least, they only appear with the feeble intensities which they have in the arc spectrum, while the characteristic arc lines are strong. Here then we find the cause of the dissimilarity of the chromospheric and Fraunhofer spectrum, which is indicated by the following figures :—

No. of Fraunhofer lines tabulated by Rowland in the region F to K	5694
No. of lines photographed in the same region, eclipse 1893	164
Percentage of Fraunhofer lines	3 per cent.
No. of lines photographed in the same region, eclipse 1896	464
Percentage of Fraunhofer lines	8 per cent.

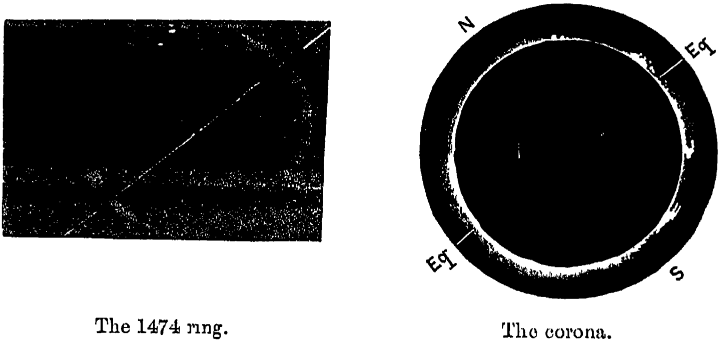
Clearly, then, the chromosphere, as photographed in the eclipses of 1893 and 1896, is a region of high temperature, in which there is a corresponding simplification of spectrum as compared with the cooler region in which the Fraunhofer absorption is produced. The spectrum of the chromosphere is to that of the sun generally as is the spectrum of α Cygni to that of Arcturus.

It is obvious that if we can succeed in 1898 to get similar records *with double the dispersion,* an immense stride will have been made, and hence the programme for the coming eclipse to which I shall have to draw attention.

CHAPTER XI.—THE SPECTRUM OF THE CORONA.

I HAVE already stated that one great advantage possessed by the prismatic camera is that it has enabled us to distinctly separate the spectrum of the corona from that of the chromosphere. It has done this because the coronal radiations are *not* most intense near the prominences; further, they seem quite separated from them, and are strongest near the equator.

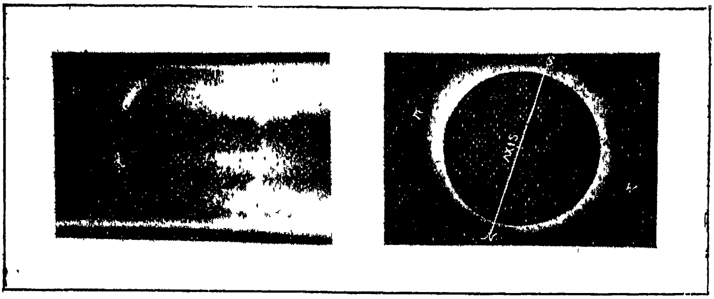
This was first revealed in the photographs of the eclipse of 1893, as the following woodcut showing photographs of the ring built up by the 1474 K light and the lower corona side by side clearly demonstrates.



The 1474 ring. The corona.

FIG. 41.—The 1474 K ring and corona of 1893

In Chapter IX I have already given one of the photographs taken by Mr. Shackleton during the eclipse of 1896, in Novaya Zemlya, showing the *dissimilarity* between the 1474 K ring and the H and K rings. The following illustration will demonstrate the *similarity* between the 1474 K ring and the corona of 1896.



The 1474 ring. The corona.

FIG. 45 —Comparison of the 1474 ring with the corona of 1896.

The ring in the green is not the only one seen.

The wave-lengths of the coronal radiations so far detected are as under, the numbers following them indicating the number of African photographs in which they have been detected. It will be seen that one ring is seen in six photographs.

Wave-length, Rowland.	
3987	(6)
4086	(4)
4217	(2)
4231	(5)
4240	(1)
4280	(2)
4486	(3)
5316·9 / 1474 K	(5)

It is almost impossible to form any trustworthy estimate of the relative intensities of the rings, but it may be noted that the one at wave-length 3987 comes next to 1474 K in order of

brightness. There are indications of other extremely faint rings, the positions of which cannot be determined with the necessary degree of accuracy to enable a useful statement to be made touching their wave-lengths.

In the case of the rings, the evidence that they truly belong to and define for us the spectrum of the corona is absolutely conclusive.

Except in the case of the ring in the green at 1474 of Kirchhoff's scale the rings are very feeble, and their wave-lengths can, perhaps, not be depended upon to within one-tenth metre. They were read off from the African negatives by direct comparison with the spectrum of Arcturus. Owing, possibly, to the great intensity of the continuous spectrum, the Brazilian negatives show only the green ring.

Coronal rings, other than those due to 1474 K, or to hydrogen, have not previously been recorded by the prismatic camera, though some of the lines corresponding to them appear to have been photographed with slit spectroscopes. The rings photographed in 1893 are compared in the following table with the results obtained by the slit spectroscopes in the years 1882, 1883, 1886,[1] and 1893,[2] those lines only which are possibly common being included :—

Prismatic camera, 1893 λ R.	Slit spectroscopes, 1893. λ A°.	Slit spectroscopes, 1886. λ A°.	Slit spectroscopes, 1883. λ A°.	Slit spectroscopes, 1882. λ A°.
3987	3986 ·4	3985 ·0 (1)[3]	3986 ?	
4086	..	4084 2 (4) 4089 ·3 (4)	} 4085	4085
4217	..	4216 ·5 (3)		
4231	..	4232 8 (5)		
4240	..	4241 (4)	..	4241
4280	4279 ·7	4280 ·6 (4)	4279	
4486	..	4485 ·6 (3)		

[1] *Phil. Trans.*, 1889, A, p. 335.
[2] *Proc. Roy. Soc*, vol. lvi, p. 20.
[3] Intensity on a scale where 6 = brightest line.

We see then that all the coronal radiations above referred to probably correspond with lines photographed by Dr. Schuster in 1886. The intensities, however, are not the same.

The number of coronal rings recorded with the prismatic camera is very much smaller than the number of lines attributed to the corona photographed with the slit spectroscopes in that and previous eclipses. This is, no doubt, partly due to the rings being submerged in continuous spectrum, which is relatively more intense in the case of the prismatic camera. Further, as already pointed out, it is not yet established that many of the lines recorded in the corona by the slit spectroscopes may not be due to chromospheric glare.

By a comparison of the results obtained with slit spectroscopes and prismatic cameras, it would seem to be possible to determine which of the lines recorded by the former instruments really belong to the coronal spectrum. The most intense light will give the strongest glare, and, therefore, the brightest lines of the chromosphere and prominences will become superposed on those due to the corona. As the results obtained with the prismatic cameras are so very definite with regard to the spectrum of the chromosphere and prominences, it seems only necessary to subtract the common lines recorded by the two instruments from the number recorded by the slit spectroscopes in order to determine those which certainly belong to the corona.

An attempt has been made to investigate the coronal spectrum in this way by reference to the slit spectra of 1886 and 1893, but no satisfactory results can be obtained until slit spectra, taken with greater dispersion, become available, and also, in the absence of more exact knowledge as to the wave-lengths of the radiations producing the rings, it is not yet possible to determine if they are represented by dark lines in the Fraunhofer spectrum, but it can already be stated that, if present at all, they are among the feeble lines.

A point of some importance is the apparent absence of the

1474 K ring from the spectra of the chromosphere and prominences. Its absence from the prominence spectrum was noted by Respighi in the eclipse of 1871. I am not aware of any observation in which the *form* of a prominence has been observed in 1474 light. All these facts seem to indicate that when the 1474 line is observed at the sun's limb without an eclipse, the spectrum of the corona itself is under examination, under the same conditions as those recorded in the eclipse photographs.

Of the other coronal rings photographed in 1893, those at wave-lengths 4217 and 4280 are approximately coincident with feeble prominence radiations; but since the other coronal rings are not represented in the prominences, the coincidences may be regarded as accidental.

Although H and K are by far the most intense of the radiations of the prominences, on no occasion have they been photographed as rings in the spectrum of the *corona* by the prismatic cameras. They have, however, been occasionally recorded as corona lines with slit spectroscopes; but it does not seem improbable that in most cases they were produced by chromospheric light scattered by our atmosphere, as before explained—light of which the prismatic camera takes no account

Perhaps the most decided evidence in favour of the existence of H and K in the corona spectrum is that depending upon the photographs taken with slit spectroscopes in 1886; Dr. Schuster states that—

> "The lines end sharply with the corona, and we must conclude, therefore, that in spite of the unfavourable atmospheric conditions, there was but little light scattered by our own atmosphere in the neighbourhood of the sun"

But in spite of this observation, Dr. Schuster has concluded that H and K "do not form part of the normal spectrum of the corona;"[1] it has been seen that the prismatic camera strengthens this conclusion.

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[1] *Phil Trans.*, vol. clxxx, A, p. 341.

The photographs taken with the prismatic cameras in 1893 show a pretty strong "continuous" spectrum, but it has already been explained that this appearance may have been produced by a very complicated spectrum, such as that which I observed in the corona in 1882. Concerning my observations, I wrote:—[1]

"Instead of the gradual smooth toning seen, say, in the spectrum of the limelight, there were maxima and minima, producing an appearance of ribbed structure, the lines of hydrogen and 1474 being, of course, over all. This observation, however, requires confirmation, for the look I had at the corona spectrum was instantaneous only."

A change in the spectrum of the corona was placed beyond all doubt in my own mind by my observations in 1871 and 1878. With reference to this I wrote as follows in 1878:—[2]

"The utter disappearance of the large bright red corona of former years in favour of a smaller and white one in this year of minimum struck everybody. Indeed, it is remarkable that, after all our past study of eclipses, this last one should have exhibited phenomena the least anticipated. It isolates the matter that gives us the continuous spectrum from the other known constituents. The present eclipse has accomplished, if nothing else, the excellent result of intensifying our knowledge concerning the running down of the solar energy. On the former occasion, in 1871, the 1474 ring was very bright, but in 1878 I did not see it at all."

As the sun-spot period is one of about eleven years, it was to be expected that the conditions of 1871 would be repeated in 1882 and 1893, and during both these eclipses the 1474 ring was photographed with the prismatic cameras. The photographic plates employed in 1875 and 1886 were not sensitive to the green, and, since no eye observations were made, we have no evidence as to the visibility of the 1474 ring in those years.

Although there can be no doubt as to a more or less regular change of intensity in the case of 1474 K, the evidence with regard to other radiations is less conclusive.

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[1] *Proc. Roy. Soc.*, vol. xxxiv, p. 299.
[2] *Nature*, vol. xviii, p. 460.

CHAPTER XII.—THE STRUCTURE OF THE SUN'S ATMOSPHERE.

THE INTERPRETATION OF PHOTOGRAPHS.

So far we have seen that the prismatic camera, when constructed of suitable dimensions, is capable of giving us priceless records relating to the spectra of the chromosphere and corona, and therefore most valuable aid in the study of all questions dealing with the *chemical* structure of the sun.

But it is capable of giving us help in another direction also. I refer to the *physical* structure of the sun's atmosphere, a matter concerning which at present we know very little.

In Figs. 12 and 13 I have reproduced two actual records of eclipse phenomena obtained by the prismatic camera or slitless spectroscope. It is first necessary to contrast these records with those given by slit spectroscopes, in which an object-glass is employed to form an image of the eclipsed sun upon the slit. Having done this we shall have then to consider the phenomena which might be expected under the most probable conditions of solar structure in both instruments. We have in fact to *interpret* the photographs.

I will take the corona first.

For the discussion of the advantages of the different methods of work in the case of the corona, it is necessary to consider the possible sources of light which are to be found in the neighbourhood of the corona. From previous experience we know that the chief sources are as follows:—

(*a*) Intrinsic light of the corona, giving the so-called continuous spectrum.

(*b*) Intrinsic light of the corona, giving bright lines.

(*c*) Light of the sun reflected by the solid or liquid particles in the corona.

(*d*) Light scattered by the particles in our own atmosphere, giving frequently the lines of the chromosphere and prominences.

It is evident that a slit spectroscope must integrate all these spectra, so that in discussing any particular line it is very difficult to know to which origin it should be ascribed. For example, if we suppose the corona to give a spectrum of hydrogen, the lines will be superposed upon lines of hydrogen due to the light of the prominences scattered by our atmosphere, and it would not be safe to draw any conclusion as to the presence or absence of hydrogen in the corona.

The advantages of the slit spectroscope in regard to the corona may be stated as follows:—

(1) If the spectrum of the corona consists of a large number of lines of nearly equal intensity, the slit spectroscope will show them more clearly than the prismatic camera, for the reason that, with the latter instrument, the overlapping of the rings would have a greater tendency to give the spectrum the appearance of being continuous. With a wide slit this advantage of the slit spectroscope would be diminished.

(2) Feeble corona lines have a greater chance to show themselves with the slit spectroscope, since it only takes account of a very small area giving continuous spectrum, while, in the prismatic camera, the continuous spectrum from adjacent parts is superposed, with the result that there is a greater tendency to masking of bright lines. The use of greater dispersion in the case of the prismatic camera would tend to remove its deficiency in this respect.

(3) The slit spectroscope will give well-defined spectra, due

to the solar light reflected by the corona, as observed by Janssen in 1871, while, in the prismatic camera, the corresponding dark rings will be too diffuse to show themselves, for the reason that they come from so large an area.

I next pass to the chromosphere and prominences.

The advantages of the slitless spectroscope, in the case of the chromosphere and prominences, may be summarised as follows:—

(1) Production of actual pictures. Unlike the slit spectroscope, it does not give the spectrum of one section only of the corona and prominences, but combines the functions of a

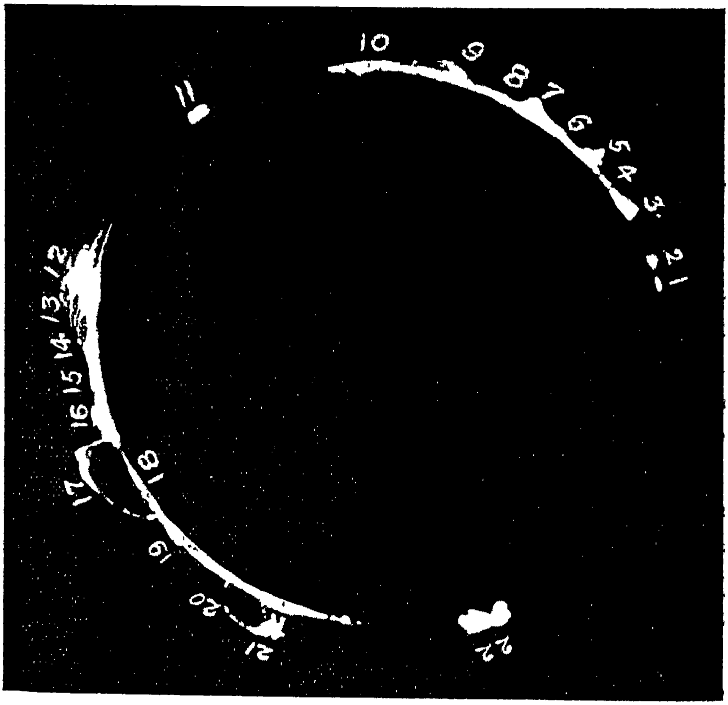

FIG. 46.—Composite photograph of the prominences seen in the eclipse of 1893 as depicted by the prismatic camera.

telescope with those of a spectroscope, and gives actual views of the whole of the solar surroundings in each radiation strong

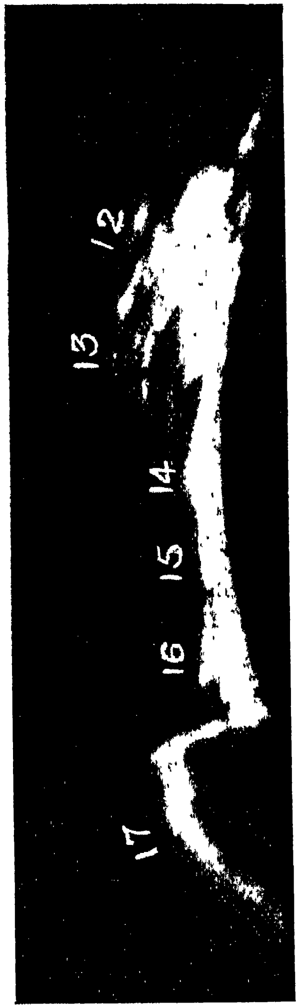

FIG. 47.—Photographic enlargement of prominences 12—17 as depicted by the prismatic camera

enough to produce an image. Any chemical differences which there may be between different regions will be shown by the

limitation of some of the spectral features to certain segments of the rings.

I can illustrate this by references to the results of the 1893 eclipse. At the beginning of totality we get a long range of prominences visible on one side of the sun; after these are covered up by the moon, near the end of totality, those on the opposite side are revealed.

In Fig. 46 the prominences photographed at these two times are shown together by simply combining the photographs.

The next illustration is an untouched enlargement of the group of prominences 12—17.

(2) Prominences will be localised by the prismatic camera, so that their separation from the normal corona spectrum will be greatly facilitated. The superposition of such a spectrum upon those due to other sources, when a slit spectroscope is employed, prevents their recognition as local phenomena.

(3) Elimination of the light from the prominences and corona scattered by the dust particles in our air. This light, though producing false lines in the spectrum of the corona, and even across the dark body of the moon itself, when a slit spectroscope is employed, cannot by any possibility produce more than a general illumination of the field when viewed through a prismatic camera. Images of the corona can only be depicted by true coronal radiations, or by radiations from the lower parts of the sun's atmosphere reflected by the corona itself, if such reflected radiations be possible.

(4) There is a great saving of light due to the absence of condensing lens, collimating lens and slit, so that photographs may be obtained with shorter exposures, and, therefore, at a greater number of stages of the eclipse.

COMPARISON OF RESULTS IN THE CASE OF ATMOSPHERIC LAYERS.

In a paper communicated to the Royal Society in 1882,[1] I pointed out the importance of considering the conditions under which we observe the phenomena of the sun's atmosphere. It was shown that whether the sun's atmosphere be composed of concentric layers of different composition, or of vapours all of which rest on the photosphere and thin out at different heights, the phenomena observed with a slit spectroscope will, *in the main*, be the same in both cases, for the reason that we have to deal with the projection of a sphere and not with a section. The only criterion is that if the vapours rest on the photosphere, the lines will thicken towards the base, whereas, in the case of a separate higher layer they would not widen or brighten towards the base, but really be thickest at the top, if we do not take account of effects of temperature. Taking temperature into consideration, as the lines will be less bright as the distance from the sun is increased, and, consequently, the temperature reduced, the lines produced by the higher layers will be of equal brightness throughout, and dimmer than the others. Accordingly the slit spectroscope can only give information as to the distribution of vapour in the sun's absorbing atmosphere by means of these very delicate observations of brightness, or widening of the bright lines observed.

Somewhat similar difficulties are met with in the case of the prismatic camera, when we attempt to distinguish between the two kinds of layers. First, consider the effects during totality. In the case of a vapour extending down to the photosphere, we should obtain spectrum rings decreasing in intensity as we pass outwards from the moon's limb. (This is exemplified by the ring obtained in the case of 1474 K, to which reference was made on p. 113, and the same appearance is seen in the case of the other coronal rings.) The apparent internal diameters of such

[1] *Proc. Roy. Soc.*, vol. xxxiv, p. 292

rings upon the photographs would be equal in every case, but their heights would depend upon the intensities of the radiations producing them. There should be no difficulty in detecting such rings unless they are of very nearly equal brightness, and very numerous, or unless they do not extend far enough to be visible beyond the moon.

There is a very definite way in which the photographs taken with the prismatic camera may indicate the presence of layers of vapours concentric with the photosphere, but not reaching down to it. At a certain height above the photosphere, the chromosphere spectrum in a photograph of the chromosphere visible at any one instant beyond the edge of the moon, will show arcs with certain relative intensities. As the moon advances and gradually uncovers the base of the chromosphere, the same arcs will remain visible, but those produced by a layer which does not extend lower down will be reduced in intensity as compared with arcs produced by vapours which do reach lower down; the latter will continue to get brighter, while the others remain of the same absolute intensity. As the lowest part of the chromosphere is shown in the photographs taken immediately after totality, or exactly at the end, it is only necessary to compare the relative intensities of the arcs in different photographs in order to investigate the general question as to the existence of layers. A large number of photographs taken in rapid succession with instantaneous exposures during the visibility of the chromosphere spectrum, either near the beginning or end of totality, would further enable us to determine the order of such layers in proceeding outwards from the photosphere.

Another way in which the prismatic camera may possibly help to determine the presence of layers is as follows. A layer concentric with, but separated from, the photosphere, will be shown in each of its radiations bright enough to be photographed, as a ring brightest at the outer edge, and dimming

very rapidly towards the photosphere in consequence of its greater thickness in the line of sight near the tangent. If only the outer part were bright enough to be photographed, the ring would have a diameter greater than that of the moon. Layers considerably removed from the photosphere would be cool and dim, and their feeble images would tend to be lost in the general continuous spectrum. The diameters of the rings being different, true wave-lengths could not be assigned, and the superposition of a great number of them would give the appearance of a nearly continuous spectrum in the part lying within the band equal in breadth to the moon's diameter. Outside this band, where the rings would be best visible, above and below the moon, on account of their different diameters, the direction of dispersion is such as to cause the greatest overlapping of images, and the consequent confusion would make the spectrum look nearly continuous, in the case of a considerable number of images. Hence there will be some difficulty in detecting the effects due to a very large number of concentric separate layers when the prismatic camera is employed during totality.

The conditions with regard to layers in the photographs taken out of totality with the prismatic camera, are somewhat as follows:—

If the vapours extend from the photosphere outwards, and are brightest at the base, the arcs due to them which appear at the cusps (provided they are bright enough to show themselves in the general illumination of the field) will have a somewhat triangular appearance, with the maximum brightness nearest to the cusp as shown at *a*, in Fig. 48.

The intensity of such an arc will gradually diminish in all directions from the cusp, and its extension will depend upon intrinsic brightness. All the arcs will have the same internal radius.

A thin layer of vapour of equal brightness throughout, and

resting on the photosphere, will give short arcs having the appearance shown at *b* in Fig. 48; as we are observing a spherical shell, the appearance would not be different from that at *a*, but the edges of the arc might be expected to be more sharply marked.

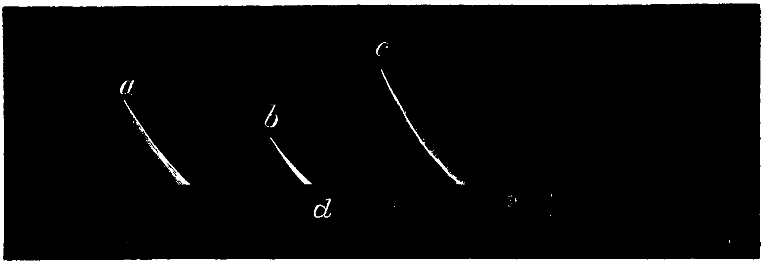

FIG. 48.—Possible appearances of bright arcs at cusp in photographs taken out of totality.

(*a*) Arc due to vapour extending from photosphere outwards, with gradually diminishing brightness.
(*b*) Arc due to a thin layer close to photosphere and equally bright throughout.
(*c*) Arc due to a shell of vapour, concentric with photosphere, but some distance from it.
(*d*) Continuous spectrum of photosphere.

In the case of a concentric shell some distance removed from the photosphere, its representative in the spectrum of the cusp will be a relatively long arc, as at *c* in Fig. 48, brightest near its outer edge, and suddenly dimming for the reason above stated.

Different layers of this kind will give arcs struck with different external radii. The arcs due to all but the brightest layers, however, will be lost in the general illumination of the field, and since the brightest vapours will be near to the photosphere, the differences of radii will not be very great, and as we are dealing with short arcs, these differences of radii will not help us to distinguish the outer shells in this way.

This suggests another consideration which may, perhaps, help us eventually, when higher dispersions are employed to

distinguish concentric shells, if they exist. As the arcs due to them are brightest on the outside, they will appear to occupy places in the spectrum which do not correspond to their true wave-lengths. At the same time they will be longer, so that it is in the case of long arcs that we might expect to find departures from the true wave-lengths. If we found, for instance, three lines near iron lines with a constant difference from the true wave-lengths of the iron lines, we should be justified in regarding such lines as iron lines displaced in the manner indicated

Comparison of Results in the case of Vapours close to the Photosphere.

The prismatic camera offers special advantages for the investigation of the vapours which lie nearest to the photosphere.

(1) The spectrum of even a very shallow layer will be represented by arcs of considerable length in a photograph taken with the prismatic camera at the beginning or end of totality, the length of the arc corresponding to the whole of the layer

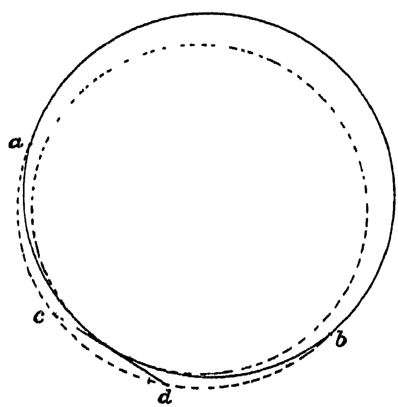

Fig. 49.—Illustrating comparative lengths of arcs and lines photographed with prismatic camera and slit-spectroscope respectively, at beginning or end of totality.

uncovered by the moon at the time. With a slit-spectroscope the lines will be relatively much shorter, even assuming that the slit can be placed exactly at a tangent to the moon's limb. This is shown in Fig. 49, in which the continuous circle represents the moon, and the dotted one the disc of the sun A layer of vapour resting on the photosphere is represented by the outer portion of a dotted circle. In the prismatic camera this layer would be represented by an arc of length *ab*, while with the slit-spectroscope, under the most favourable conditions, it will only be represented by a line of length *cd*.

No special adjustment of the instrument is necessary to enable such photographs to be obtained, whereas with the slit-spectroscope the most accurate adjustment would be necessary.

(2) The radiations of such vapours may be studied by means of photographs taken shortly before and after totality, for which no readjustment of the instrument is required. The bright arcs at the cusps are of greater length than the lines in similar photographs, which might be taken with slit-spectroscopes.

INTERPRETATION OF PHOTOGRAPHS TAKEN DURING TOTALITY.

The photographs taken during totality show the spectrum of the chromosphere and prominences as they appear at different heights above the photosphere.

Thus, the metallic prominence photographed in the eclipse of 1893, shown in the lower left-hand quadrant in Fig. 13, appears also in Fig. 12, the lower parts being eclipsed, so that it only shows the spectrum of the tip of the prominence beyond the dark moon.

In the case of the spectrum of the chromosphere, different parts of the arcs photographed correspond to the spectrum at different distances above the photosphere. Thus, at a position angle corresponding to the point of contact at the beginning or end of totality, the edge of the moon will reveal the chromosphere to a greater depth than at adjacent parts, as shown in

Fig. 50. If the inner circle represents the boundary of the photosphere, and the circle concentric with it represents the chromosphere, the edge of the moon, at the moment of contact, will be in some such position as *cab*. At the point *a* we should at that moment get the spectrum of the base of the chromosphere, while at *b* and *c* we should only get the spectrum of the higher reaches.

In case the chromosphere consisted of concentric shells of vapour, the spectrum seen at the point *a* would be the integration of the spectra of all the shells of vapour, but at *c* and *b* only the outer shells would be effective in producing a spectrum.

A point which it is important to bear in mind, when attempting to interpret the photographs taken during totality, is the production of rings by a source of light giving a purely con-

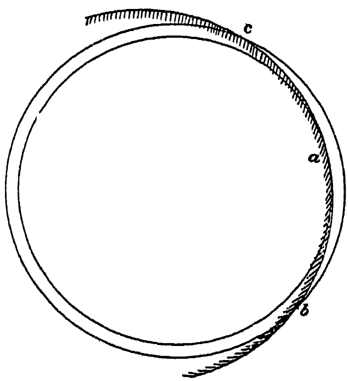

FIG. 50.—Illustrating different depths of chromosphere photographed with one exposure.

tinuous spectrum, when a slitless spectroscope is employed. Attention was drawn to this in the preliminary report,[1] and it was stated that the broad ill-defined ring, a little more refrangible than D^3 in some of the African photographs, as well

[1] *Phil. Trans.*, 1894, vol. clxxxv, A, p. 714.

as a less conspicuous one in the blue, and possibly even another in the violet, has its origin in the *continuous* spectrum of the corona acting on a plate, which has one maximum of sensitiveness

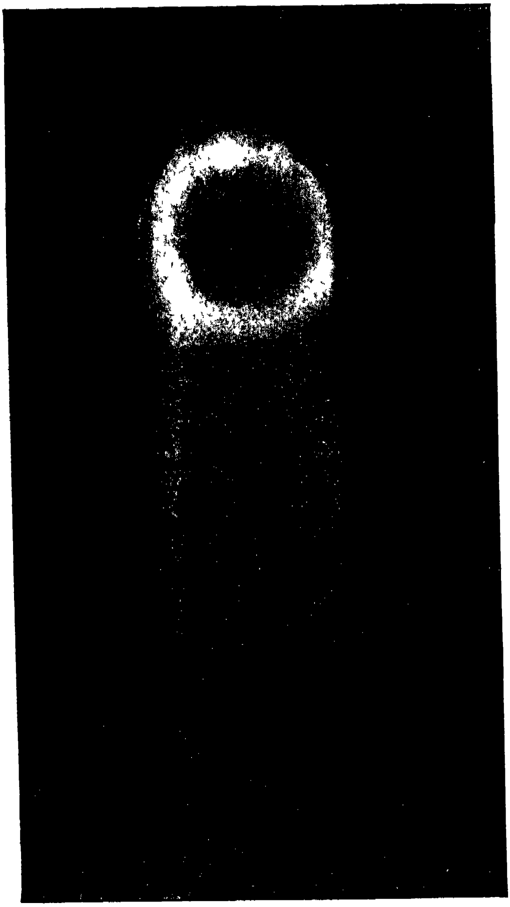

FIG 51 —Appearance of continuous spectrum photographed on an isochromatic plate with a ring slit.

for the yellow rays and one or more maxima in the blue and violet. Experiments with ring slits, illuminated by a source of light giving a continuous spectrum, have confirmed this explanation. The photograph reproduced in Fig. 51 was taken on an

isochromatic plate with the 6-inch prismatic camera, temporarily provided with a $3\frac{1}{2}$-inch collimator in which the slit was replaced by a positive picture of the corona. A bull's-eye lamp was employed as a source of light, and it will be seen that although there was no suspicion of anything but continuous radiations, an appearance of rings was produced exactly resembling those to which reference has been made as taken during the eclipse.

INTERPRETATION OF PHOTOGRAPHS TAKEN OUT OF TOTALITY.

The photographs taken out of totality greatly increase the chances of obtaining a record of the spectra of the vapours near the photosphere. It is evident that shallow strata can only be visible for a very short time after the beginning and before the end of totality, but they will be visible *at the cusps* out of totality, so long as the general illumination of the sky by the uneclipsed part of the photosphere is insufficient to mask them.

Fig. 52 will facilitate a general explanation of the photographs taken out of totality. The part of the diagram to the left represents the relative positions of the sun and moon at the African station about a minute after totality, there being a thin crescent of photosphere then visible in the south-west quadrant. Two imaginary layers of vapour are drawn round the sun. The direction of dispersion being north and south, the spectrum is drawn out in the direction indicated by the continuous spectrum in the part of the diagram on the right. It is evident that the radiations of the outer layer of vapour will be represented by long arcs in the spectrum of the cusp, while those proceeding from the lower vapour will be represented by shorter ones.

It may be remarked also that the lengths of the arcs at the cusps for any particular layer of vapour will depend upon the interval from totality at which the photograph is taken; even a shallow layer will be represented by long spectrum arcs at

the moments of 2nd and 3rd contacts, but the lengths of these will be gradually diminished in consequence of the less oblique section of them which is made by the moon as totality is departed from.

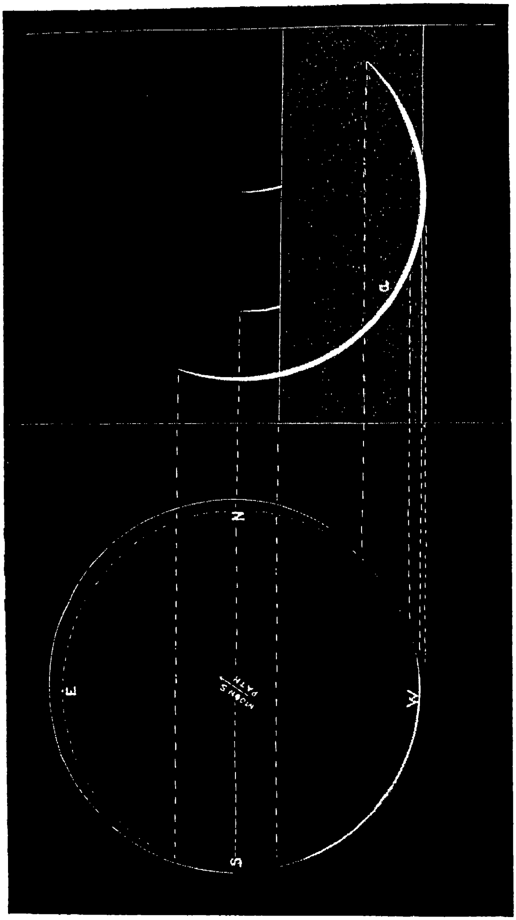

FIG. 52.—General explanation of photographs taken out of totality in 1893.

If the vapours are evenly distributed in the layers the arcs at the cusp will be geometrically regular, but if they are disturbed, as we have reason to believe they may be, the forms of

the arcs may not be regular, and they may be of unequal brightness in different parts.

Although irregularities of the vapours may be distributed all along the sun's limb, the conditions under which they are presented to us will vary with the distance from the cusp, just as in the case of uniform layers. A knot near the cusp would be fully revealed to us, and the prismatic camera would give us the spectrum of all its parts. A knot a little removed from the cusp, however, will have its base covered by the moon's edge, and only the spectrum of its higher parts will be seen. Taking the spectrum generally, it will have four origins:—(1) The spectrum of the vapours of the cusps, giving bright arcs; (2) the spectrum of the visible crescent of photosphere, consisting of a bright continuous spectrum crossed by dark arcs; (3) the spectrum of the vapours surrounding the uneclipsed part of the sun, giving bright arcs; (4) the spectrum of the corona, consisting of a relatively feeble continuous spectrum and a number of bright rings.

CHAPTER XIII.—THE APPROACHING TOTAL ECLIPSE IN INDIA.

THE failure of so many of the eclipse parties last year to secure observations, makes it a matter of congratulation that the weather prospects of the eclipse to be observed in India on January 22 next year seem to be as favourable as they possibly can be. I propose in the present chapter to refer generally to the objects to be attained, and to give an account of the proposed arrangements so far as I know them. To show how fair the prospect of success this time is, I will begin by referring to a note drawn up by Mr. Eliot, F.R.S., Meteorological Reporter to the Government of India, in order to give the chief meteorological features of the tract of country in India through which the line of totality will pass.

The note begins by giving a general idea of the Indian climate:—

"It may be premised that the year in India may be divided into two seasons or periods—the north-east or dry monsoon (or season), and the south-west or wet monsoon. During the south-west monsoon winds of oceanic origin prevail, and the whole of the period is one of frequent rain over the greater part of India. The chief features of this period, lasting from June to December, are moderately high temperature, moderate diurnal range of temperature, high humidity, much cloud, and more or less frequent rain. The amount of cloud and rain differ very considerably in different parts of the country, depending upon their position with respect to the neighbouring seas and the mountain ranges in India, and other conditions. The south-west monsoon winds usually withdraw from

Northern India in September or October, and from the Bay of Bengal and Southern India in December. Hence the months of November and December form a transition period from the conditions of the wet to the dry monsoon, the change commencing in Upper India, and extending slowly eastwards and southwards.

"During the dry or north-east monsoon (extending from January to May), winds of land origin prevail in the interior of India. In Northern India these land winds blow down the larger river valleys, and are hence westerly over the Gangetic plain, the largest river plain in India.

"The first two months, January and February, form the cool weather of Northern and Central India and the Deccan. The mean temperature of the day ranges between an average of 71° in the Deccan (Berar, the Central Provinces, and Hyderabad), and 54° in the Punjab. The diurnal range of temperature is large in amount, varying between 25° to 35° or 40° in the interior. The air is usually very dry, skies free from cloud, and winds light, more especially in the Punjab and more remote districts of the interior. The disturbances of this period are feeble cyclonic storms of large extent, which cross Northern India from west to east, and give much cloud and light, to moderate, rain in the plains and hills of Northern India. Temperature increases rapidly in March, and that month and the two following months of April and May form the hot weather season. The intensity of the hot weather conditions increases from March to May. The chief features of the weather of this period in the interior of India are high day temperature, large diurnal range of temperature, great dryness of the air, and strong day winds which raise clouds of dust, and more or less obscure the sky and sun. Cyclonic storms of large extent are of comparatively rare occurrence in this period. On the other hand, small local hot weather storms—including hailstorms, thunderstorms, and duststorms—are of frequent occurrence and tornadoes are of occasional occurrence, in Bengal chiefly."

It follows from this sketch that the eclipse will occur in the middle of the cold weather and at the most favourable time of the year for travelling in India. Light north-east winds, fine weather, and smooth sea are to be expected. Cyclonic storms are of exceedingly rare occurrence in either sea during the month, and the chance of a gale or of stormy weather in the month off the coast of the Konkan (from Bombay to Karwar) is, according to Mr. Eliot, less than 1/50. He states:—

"The weather is throughout the month of January almost uniformly

fine, with clear or lightly clouded skies over the whole of the Peninsula. Light north-easterly to easterly winds obtain in the Deccan or interior of the Peninsula. The west coast districts are protected by the West Ghats from these winds, and light land and sea breezes prevail. The most remarkable feature of the meteorology of the coast area from Bombay south to Karwar in January is the freedom of the skies from cloud. Disturbances are of very rare occurrence, and fine weather is hence almost a certainty during the whole of the month. There is, however, usually much dust in the air, raised by the dry winds in the Deccan."

Among other most important matter in Mr. Eliot's note is a table showing average temperature, humidity, cloud and rainfall data in January at certain stations in India near the line of totality. We gather that the mean temperature of the month of January in the Konkan coast districts is 76°, with a diurnal range of 20°. In the Deccan (*i.e.*, at Sholapur, &c.) and the Central Provinces the mean temperature of the day in January is approximately 70°, and the diurnal range nearly 30°. In Bihar the mean daily temperature of the month is 62°, and the diurnal range 23°.

Mr. Eliot points out that since the air is very dry over the interior, and the mean daily humidity percentages at stations in the Deccan, Central Provinces, and Berar averages about 40°, any instruments brought out from Europe, such as photographic cameras, &c., should be constructed to withstand the action of this great dryness of the air. With regard to cloud, the data show that the coast districts between Karwar and Ratnagiri (which includes the line of totality) is on the mean of the month more free from cloud than any other part of the line of totality.

"The amount of cloud is practically uniform in amount over the Deccan and Central Provinces, and is slightly greater in Bihar than in the Deccan or Central Provinces. The amount of cloud is very large at Darjeeling in January, and mist or fog almost invariably forms after clear nights in the morning (about 9 or 10 A.M.), and prevails more or less steadily until late in the afternoon, when it gradually disappears."

Rain is of rare occurrence during the month of January in

the Konkan and Deccan. Its probability increases in proceeding from west to east. In the Konkan the average number of rainy days in the month is only 0·2, and in the eastern districts of the North-western Provinces the average number is 2, and in Bihar 1·2.

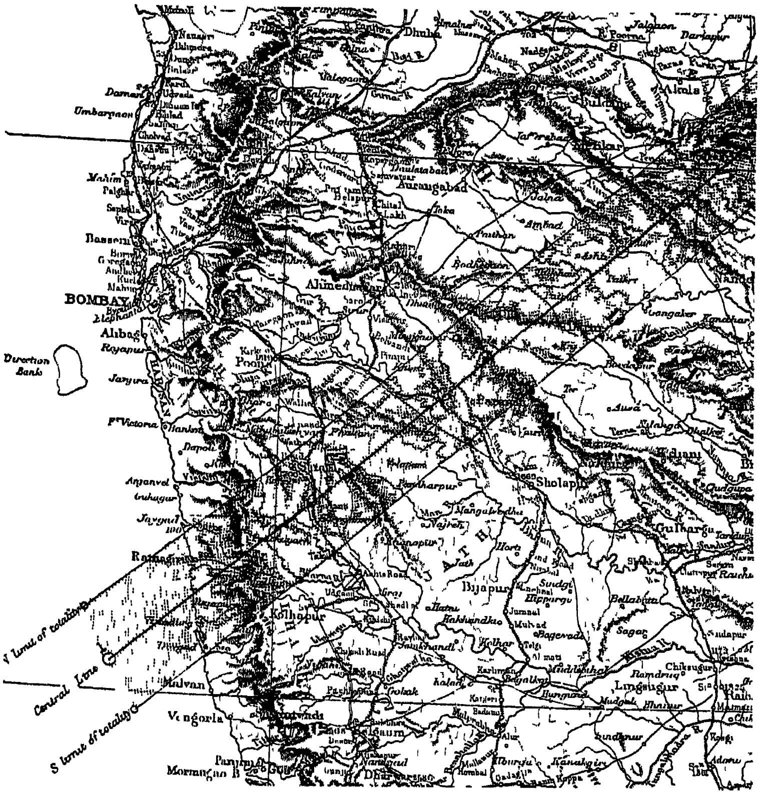

FIG. 53.—The central line of Eclipse in Western India.

"The probability of a rainy day in January is hence about six times as great in Bihar as in Konkan. The probability of any given day in January being rainy in the Konkan is less than 1/150, and in Bihar 1/25."

Mr. Eliot remarks, in connection with this, that skies are usually remarkably clear after rain in the Gangetic plain, and the atmospheric conditions for astronomical observations are at such times much finer than are ever obtainable in the Konkan or Deccan.

The weather chances for the Eclipse, it will be seen, according to Mr. Eliot, one of the highest meteorological authorities, are about as good as they possibly can be. The authorites in India and the railway companies are showing themselves willing to assist intending observers. The Asiatic Society of Bengal has spared no pains in collecting and disseminating information for the use of those visiting India on the occasion, and be it not forgotten that India in the cool season is reached over tranquil seas and presents one of the finest climates in the world, to say nothing of what Nature provides in the way of tropical scenery, and successive dynasties have left behind them in the way of monuments which are among the wonders and delights of the world.

With regard to the getting there and travelling when there, I may refer to an article by my old friend, Professor Pedler, which he has recently written in *Nature* on this subject. It is full of valuable information.

The local astronomical conditions at three points along the line of totality are thus stated in the "local particulars" issued from the Nautical Almanac Office. Local mean times and the points of contact for direct image are given.

RAJAPUR, Long. 73° 35′ E., Lat. 16° 40′ N.

		d	h.	m.	s.	Contact from N. Point.	Contact from Vertex	Sun's altitude.
Eclipse begins	January	21	23	13	58	121° W.	100° W.	52°
Totality begins	"	22	0	47	42	Duration 2m. 1·9s.		53°
Totality ends	"	22	0	49	44			
Eclipse ends	"	22	2	15	51	55° E.	13° E.	44°

NAGPUR, Long. 79° 8′ E., Lat. 21° 9′ N.

	d.	h	m.	s	Contact from N. Point.	Contact from Vertex.	Sun's altitude.
Eclipse begins January	21	23	56	20	123° W.	118° W.	50°
Totality begins „	22	1	26	33	Duration 1 m. 17·7s.		46°
Totality ends „	22	1	27	51			
Eclipse ends „	22	2	49	15	55° E.	10° E.	35°

POSITION SOUTH OF BENARES, Long. 83° 0′ E., Lat. 24° 40′ N.

	d	h.	m.	s	Contact from N. Point.	Contact from Vortex.	Sun's altitude.
Eclipse begins January	22	0	24	56	123° W.	128° W.	46°
Totality begins „	22	1	51	28	Duration 1 m. 43·6s.		40°
Totality ends „	22	1	53	12			
Eclipse ends „	22	3	10	48	56° E.	10 E°.	29°

The Joint Committee of the Royal and Royal Astronomical Societies have determined to send out three parties to observe, one on the coast and two inland, at stations to be subsequently decided upon. It has been arranged that the party from the Solar Physics Observatory will occupy the coast station, and the Admiralty has granted the use of a man-of-war to allow an attempt to be made to repeat the "Volage" programme of 1896.

The station will possibly be in or near the old fort at Viziadurg for which point the following astronomical conditions hold, according to the Superintendent of the *Nautical Almanac* (Fig. 27).

Assuming the position of Viziadurg to be 16° 32′ N., and 73° 22′ E., the times of contact are (local mean time):—

	d.	h.	m.	s.	
1898.—January	21	23	12	20	
„	22	0	46	9	$P_2 = 241°$
„	22	0	48	14	$P_3 = 51°$
„	22	2	14	33	

These times are 4 h. 53 m. 28 s. in advance of Greenwich.

The land parties—which will include the Astronomer Royal,

Dr. Copeland, Professor Turner, and Mr. Newall, representing the Observatories of Greenwich, Edinburgh, Oxford and Cambridge, together with Dr. Common and Captain Hills—will occupy stations near the central line on the railways shown on the map (Fig. 53).

The recurrence of an eclipse in India in 1898 carries me back vividly to the eclipse of 1871, also observed in India.

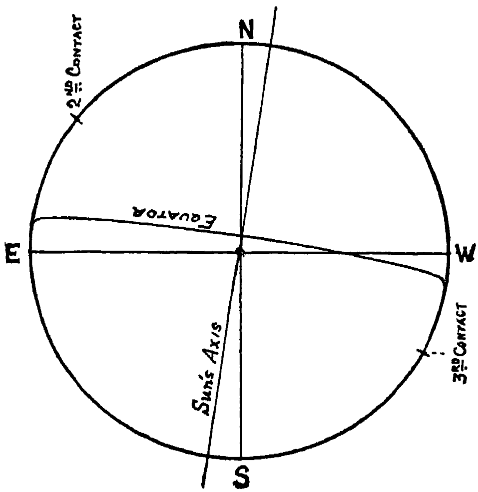

FIG. 54.—The conditions of observation at Viziadurg.

The shadow path of the eclipse of that year cut the west coast of India, but at a much more southerly point than Viziadurg. The coast station was then Baikal, and from this point the shadow swept over the land in a south-east direction, as shown in the accompanying map.

The retrospect is very encouraging, for one is reminded of the enormous advance in our knowledge of the sun since that time; and more than this, we have now the supreme advantage that eye observations have been almost entirely superseded by permanent photographic records. The accompanying photograph of one of the "drills" at the Eclipse Camp at Baikal in

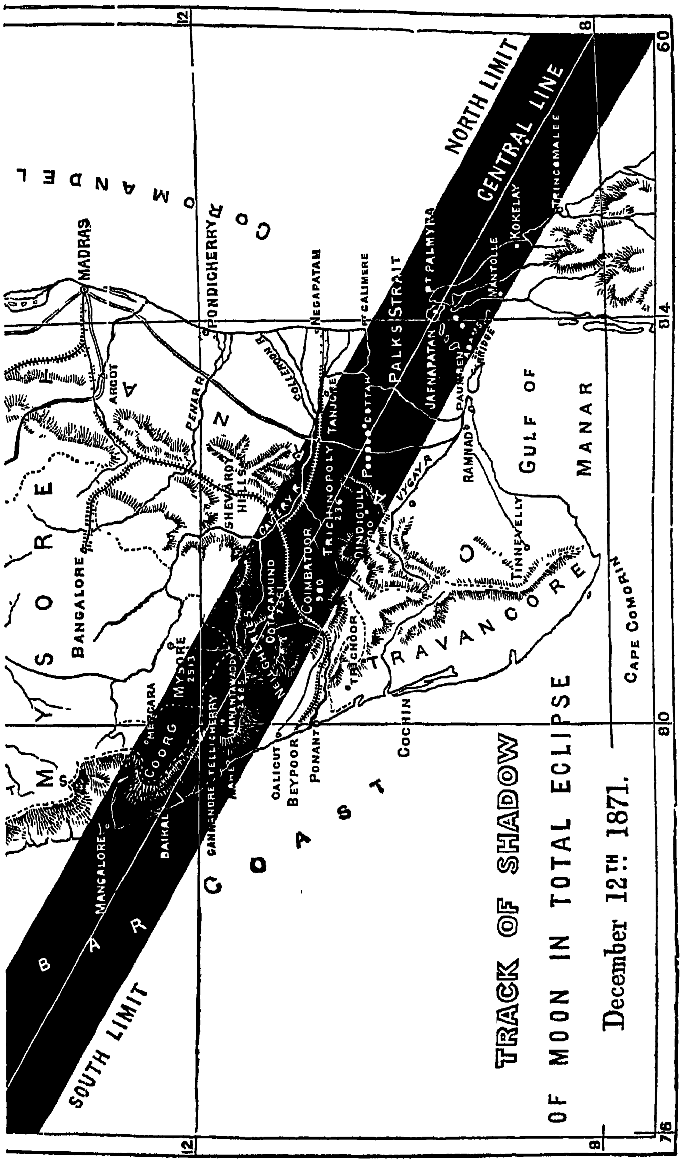

FIG. 55.—Path of Eclipse 1871.

1871 will show that eye observations of the spectra alone were attempted, and that the attack was vastly different from that

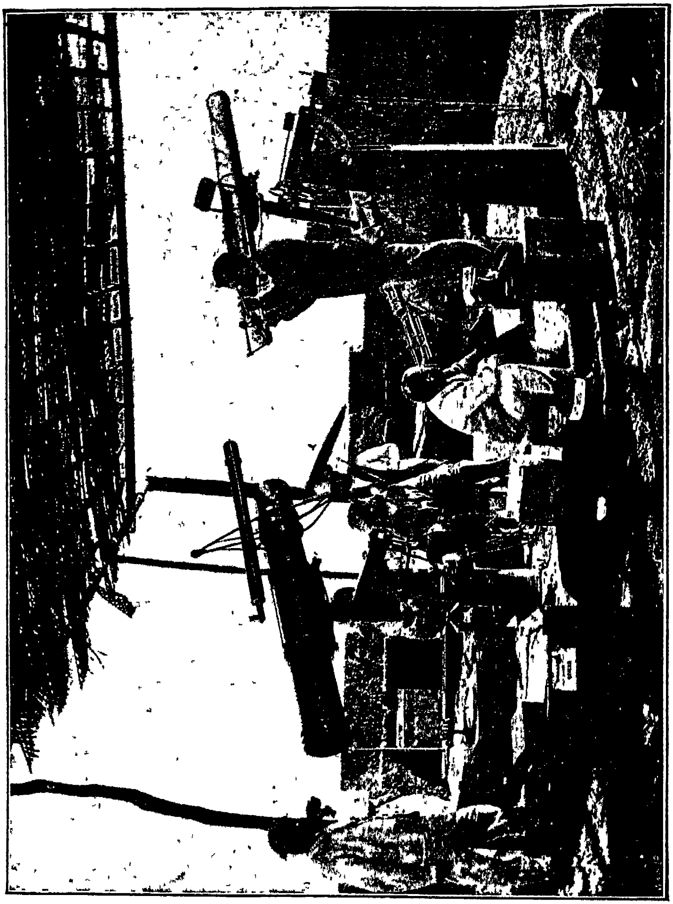

FIG. 56.—The spectroscope observatory at Baikal in 1871.

already depicted at Kio last year. It must also be remembered that none of the laboratory experiments referred to in Chapter X had then been made.

CHAPTER XIV.—THE WORK TO BE DONE DURING THE INDIAN ECLIPSE.

THE PROGRAMME OF THE COAST PARTY.

WITH the good weather chances and the present facilities of travel referred to the last Chapter, we are justified in anticipating much valuable work being garnered next year, both by the Indian astronomers interested in solar physics—foremost among whom we must name Professor K. D. Naegamvala, who has already done good work at Poona—and those who visit India for the purpose.

With regard to the work to be attempted in 1898 by the coast party, to which I propose to confine myself, I may state, in the first place, that I am one of those who believe that spectroscopic observations during eclipses must take precedence of all others in the minds of students of solar physics; but when I say this, it must not be forgotten that other inquiries remain which are much more simply carried out, and are within the competence of those unacquainted with the details of the subject; one of the fortunate things about eclipses is that photographers and amateurs can do good work as well as those more fully equipped instrumentally.

With regard to the work I propose to attempt in India, the following extracts from a letter I was called upon to write some time ago, still express my views. These are based upon the results obtained with the prismatic cameras in 1893 and 1896, which, although they are not yet fully worked out, in my

opinion far transcend in importance any observations made on the eclipsed sun since 1868:—

"(1) I propose in 1898 to use a prismatic camera with double the present dispersion, although the dispersion employed by me in 1893 and 1896 was, I believe, far beyond anything obtained before.

"The facts are as follows. With the 6-inch prismatic camera used in 1893, the photographed spectrum was 3·1 inches long from D to K. With the 9-inch, which it was proposed to employ in 1896, the corresponding length of spectrum was 3·9 inches; while with the 3-inch prismatic camera actually used in Novaya Zemlya, the spectrum was 2·9 inches long from D to K.

"I believe the next highest dispersion obtained before was by Captain Hills, in 1893 and by Dr. Schuster, in 1886. Data are not available for exactly comparing the dimensions of the spectra then photographed with those stated above, but they were certainly considerably smaller in both cases.

"The imperative necessity for this increased dispersion may be gathered from the following facts concerning the spectrum of iron which I have best studied, and on which I have thousands of unpublished observations to compare with an eclipse spectrum when we can get one on a sufficient scale.

"Taking Rowland's lines, it may be generally stated that, on an average one occurs at every 6/10 of a tenth-metre, the unit of measurement generally employed in such matters. With the dispersion in my photographs —the greatest so far obtained, as I have explained—we do not feel ourselves justified in assuming a greater accuracy than 5/10 of a unit. Evidently then, so far as this line of work alone is concerned, we can make no definite statements as to the presence or absence of iron lines in the eclipse photographs.

"So far as I am aware, no observations with the slit spectroscope will enable us to determine with any kind of exactness the relative composition of the successive layers of the sun's gaseous envelope. The difficulty chiefly arises, as I pointed out in 1882, from the fact that we have to deal with the projection of a sphere surrounded by vapours, and not with a section.

"On the other hand, the photographs taken with the prismatic cameras in 1893, and during the last eclipse, show clearly that there are essential differences in the composition of the envelopes at different levels, and the limits of various layers are indicated; but the dispersion is too small to enable us to define the chemical origins of the layers with sufficient certainty. A full statement of the evidence upon this point is included in the report on the results obtained with the prismatic cameras in 1893.

"(2) The prismatic camera has enabled us to photograph radiations at many different wave-lengths in the spectrum of the corona, differentiating them absolutely from the radiations of the chromosphere and prominences. This is a gigantic advance. But in the prismatic camera photographs, the indications, except in the case of the 1474 ring, and two or three others, are very dim.

"It is important, therefore, to employ an integrating spectroscope of large dimensions to attempt to get stronger indications of these radiations *by utilising the greater area of the corona*, which of course the prismatic camera cannot do.[1]

"(3) I may say, roughly, that in the (still unpublished) spectrum of the chromosphere obtained in 1893 and 1896, we deal with less than 10 per cent. of the Fraunhofer lines. It is of the first importance, then, to search for the others. I certainly saw some of them in 1882, but a very special inquiry is necessary. This I therefore include in my programme. These lines are certain to be dim, otherwise we should have photographed them already The tendency of the observations of 1893 and 1896 is to show that they will be found in all probability above the chromospheric layer we have photographed, and associated with the coronal layers, of which we have photographed a few of the brightest radiations.

"The thicknesses of the chromospheric layers have been:—

	1893.	1896.
H and K	less than 5000 miles	5000 miles
G	" 3000 "	
4471	" 3000 "	
Strontium line 4077 .	" 500 "	
Iron triplet	" 500 "	
Shortest arcs of Fe, &c.	" 500 "	90 miles

[1] It may be useful to point out here that there are two different ways of using an ordinary spectroscope on the sun, whether eclipsed or not.

One way consists of throwing an image of the sun (whether eclipsed or not) on the slit. In this case we observe primarily the spectrum of that part of the sun (whether spot, prominence or corona) the image of which is made to fall on the slit; still during eclipses the proviso stated on page 119 must be borne in mind.

In the other way the spectroscope is simply directed to the sun's place. In this case the light from all the various parts of the solar atmosphere seen during an eclipse, included in a circular region the angular diameter of which depends upon the diameter and focal length of the object glass of the collimator, enters the spectroscope. The resulting spectrum therefore contains the bright lines of both the lower and upper parts of the atmosphere, that is, of chromosphere, prominences and corona. In other words, the light of all these phenomena is *integrated*, hence the name integrating spectroscope.

"Beyond the dark moon, both in 1893 and 1896, we have indications of luminosity in the prismatic camera photographs, but no final statement can be made as to its origin.

"This gives us the spectrum of a part of the solar atmosphere at a great height.—

1893	....	22,500 miles to 600,000 miles.
1896	....	14,000 „ to a height not yet determined.

"This, therefore, indicates a region, some 10,000 of miles in thickness, to be also explored, and the blank in the photographic evidence so far obtained suggests that eye observations must be employed.

"It will be seen from the above statement that the three parts of the proposed inquiry are all strictly connected, and that to employ any one of them without the others would greatly weaken the attack."

It will have been gathered that the chief object of the above observations is to determine the chemical and physical conditions of that part of the sun's atmosphere just above the photosphere, and therefore including the chromosphere.

Why so much importance is attached to such observations during eclipses is that ordinary daily observations on the uneclipsed sun, although they carry us far, do not carry us far enough.

NOTES ON THE MOST IMPORTANT POINTS TO BE INVESTIGATED DURING AN ECLIPSE.

The Origin of the Fraunhofer Lines.

In Chapter X I referred briefly to the divergent views held with regard to the true *locus* of origin of the absorption which produces the Fraunhofer lines. It is, I think, worth while to return to this subject in order that the results obtained from the double series of photographs obtained during the eclipse of 1893 may be indicated. I pointed out that in the photographs in question the radiation spectrum was most distinctly *not* identical with the Fraunhofer spectrum; the most important point being that some of the strongest bright lines do not appear among the dark ones in the solar spectrum, while some

of the strongest dark lines are not seen bright in the spectrum of the stratum of vapours in immediate contact with the photosphere. The region covered by the diagram, given on page 101, lies between wave-lengths 4100 and 4300, but similar results follow when other regions are included in the inquiry.

These positive conclusions are not weakened by the consideration that the resolving power of the prismatic cameras employed in 1893 was not sufficiently great to show all the lines of the Fraunhofer spectrum, which is used as a term of comparison; in fact, working under exactly the same conditions as during the eclipse, the instrument employed in Africa only shows 104 lines in the spectra of stars resembling the sun, in the region *h* to H, in place of 940 given in Rowland's tables of lines in the solar spectrum We, therefore, get a better term of comparison if we employ the spectrum of some star such as Arcturus, which closely resembles the sun. Such a comparison is shown in Fig. 57; out of 104 lines which the instrument is capable of de-

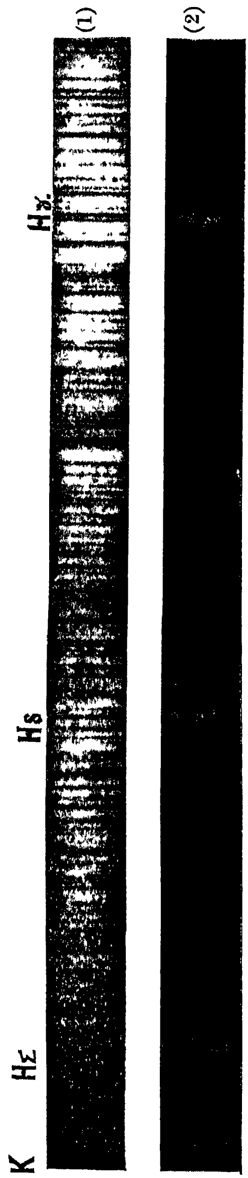

FIG. 57.—The spectrum of Arcturus (1) compared with that of the base of the chromosphere (2), photographed during the Eclipse of 1893.

picting in the region h to H, only 40 are shown in the spectrum of the base of the sun's atmosphere. This comparison amply confirms the conclusion that the lines reversed at the beginning or end of totality, though fairly numerous, do not correspond in intensity, though some of them correspond in position, with the dark lines of the solar spectrum, and consequently that the so-called "reversing layer" close to the photosphere is incompetent to produce, by its absorption, the Fraunhofer lines Further, while the chromosphere fails to show most of the lines which are present in the Fraunhofer spectrum, it shows many bright lines which are not represented among the dark ones. This again indicates that the chromosphere is not the origin of the Fraunhofer spectrum.

It is all the more important to call attention to the advantage we now possess in being able to directly compare photographs of the chromosphere obtained during eclipses with others of the spectra of stars resembling the sun, since, as I have already stated, if all goes well next year, double the dispersion utilised in 1893 will be employed. This is certain, not only to enable us to obtain more accurate results, but the number of Arcturus- and chromospheric-lines *obtained by the same instrument* will be very greatly increased.

The Spectra of Prominences at Different Heights.

There is another matter of almost equal importance in which the increased dispersion designed to be employed in 1898 will in all probability prove of the utmost value. I refer to the differences in the spectra as we work outwards from the photosphere.

The questions touching the spectra of prominences at different heights, which the prismatic camera enables us to study with minuteness, must really lead in time to a much better knowledge of the loci of absorption in the solar atmosphere.

If we consider a prominence on that part of the sun's limb where the second contact takes place, the first photograph taken during totality will show the spectrum of the whole prominence, and succeeding photographs will give the spectrum of the same prominence with the lower parts gradually cut off by the moon's edge. In the case of a prominence at the opposite limb, similar sections will be represented in successive photographs, and the last photograph taken during totality will show the spectrum of the greatest part of the prominence.

Some of the 1893 prominences (Nos 3 and 19) have been investigated in this way, and particulars of their spectra at various heights recorded. The height above the photosphere, reckoned in seconds of arc and in miles, at which each spectrum is given, has been calculated, and the relative intensities of the lines at different heights have been tabulated. In this way it has been found that some of the lines remain of the same relative intensity throughout all parts of the same prominence; others, again, dim rapidly in passing towards the upper parts, while some, but not so many, brighten.

The prominences are also seen to behave differently in respect to some of the lines; thus the line at λ 3856·5 disappears before a height of 2,000 miles is reached in prominence No. 3, but remains visible at a height of over 4,000 miles in prominence No. 19. Lines also occur in one prominence which do not appear in the other, *e.g.*, λ 4313·2. Other differences are also revealed; but it may be remarked that too much stress should not be laid on the presence or absence of the very faintest lines in some of the photographs, as variations may be partially attributed to differences in the quality of the photographs, and also to the time of exposure and degree of development.

The changes in the spectrum of a prominence in passing from the top towards the base are illustrated in Fig. 58. Spectra *a*, *b*, and *c* represent the spectrum of prominence No. 3 as it

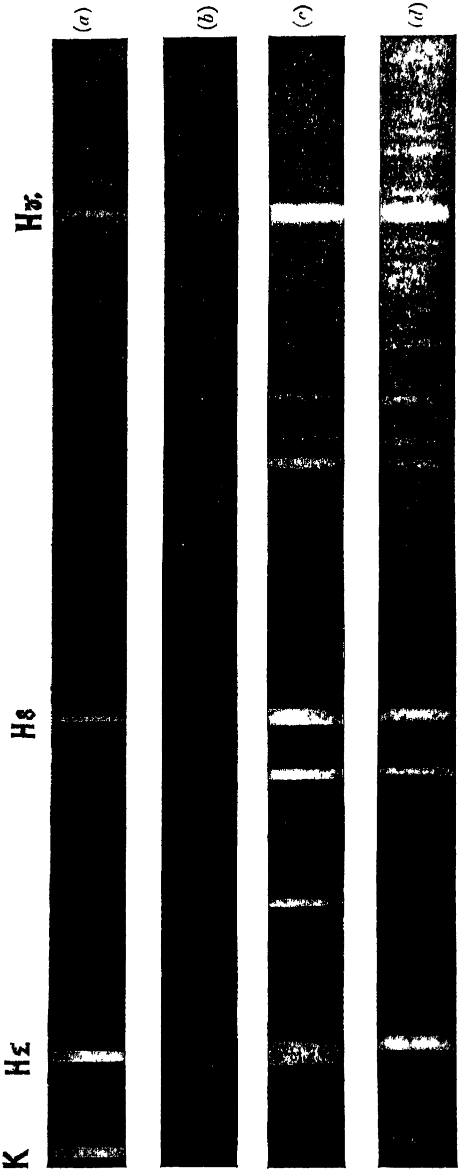

FIG. 58.—The spectra, a, b, c, of prominence No. 3, photographed during the eclipse of 1893, compared with the spectrum of the base of chromosphere d.
(a) 22—26″ above photosphere; (b) 7—9″ above photosphere; (c) 3—4″ above photosphere.

appears in the African Photographs Nos. 11, 9, and 7 respectively; the first giving the spectrum of the upper part only, while the last shows the spectrum nearer the base. Accepting the time of commencement of totality in Africa as 2h. 23m. 48s. by the deck watch, it has been calculated that spectrum *a* represents a part of the prominence 22—26″ (9,950 to 11,600 miles) above the photosphere; spectrum *b*, 6·7—8·5″ (3,000 to 3,800 miles); and spectrum *c*, 3·7″ (1,660 miles) above the photosphere. Strip *d* is the spectrum of the base of the chromosphere as represented by the cusp in the African Photograph No. 22.

These enlarged spectra have been obtained by covering copies of the original negatives with tinfoil, leaving only narrow strips showing the prominence spectra, and giving them the necessary width by moving the photograph in a direction at right angles to the length of the spectrum.[1]

The want of exact coincidence of lines common to different horizons in the copies of the photographs which I have given in Fig. 58, is due to the difficulty of obtaining enlargements on exactly the same scale. The difference in thickness of the same line in different photographs of a prominence is due to the varying widths of the corresponding images of the prominence formed by the prismatic camera at different stages of the eclipse.

In order that the changes of intensity of the various lines may be separated from the effects due to varying exposures, the individual observations are arranged in groups according to the time of exposure of the photographs.

In contrasting the spectrum of the prominences with the spectrum of the cusp, it should be borne in mind that the cusp in the African photograph specially examined (No. 22), does not represent the base of the chromosphere immediately

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[1] *Phil. Trans.*, 1893, vol. clxxxiv, A, p. 684.

beneath either of the metallic prominences. Still the cusp was not far from a prominence (No. 19), and it is fair to consider the base of the chromosphere homogeneous. If so, the prominences cannot be fed from the base of the chromosphere, since they contain different vapours.

The Spectrum of the Chromosphere at Different Heights.

But we are not limited in these investigations to the study of the prominences; we can obtain similar information from the chromosphere itself.

The spectrum of the chromosphere itself at different heights can also be partially investigated in the eclipse photographs. A considerable arc of chromosphere was photographed in one of the African negatives (No. 21). The photograph was taken about ten seconds before the end of totality, so that the lower reaches of the solar atmosphere within 1,660 miles of the photosphere were hidden. The bright arcs accordingly represent the spectrum of the chromosphere above that height. None of the photographs give us any information as to the spectrum lower down until we come to the part very near to the base which is shown at the cusp in another photograph (22). Most of the lines become relatively brighter as the base of the chromosphere is approached, but some become dimmer.

The Existence of Layers in the Solar Atmosphere.

The most direct evidence which eclipse photographs can give as to the separation of the solar atmospheric vapours into layers is that afforded by the increased relative brightness of some of the lines in passing to higher levels.

We have seen that a careful and impartial tabulation of intensities has shown that, both in the prominences and in the chromosphere, some vapours do seem to be brighter as they increase their distance from the photosphere.

As we have to deal with the projection of a sphere and not with a section of the sun's atmosphere, the spectrum arcs would brighten in passing outwards from the photosphere as already stated on page 124, in consequence of the increased thickness of vapour presented to us, even if the radiation per unit volume remained constant. The spectroscopic differences in the 1893 photographs, studied and carefully recorded, show, however, numerous inversions even in the behaviour of the same line in different prominences; so that the increased brightness observed cannot always be due to this cause alone.

Some of the lines are brightest at the base of the chromosphere, while others are brighter at greater elevations. As already explained, some of the lines which are brightest above the photosphere are probably produced by vapours existing in layers concentric with, but above and detached from, the photosphere. Those lines which become dimmer in passing outwards must owe their origin to vapours resting on the photosphere.

It will be obvious to everybody that the more the idea of the absorption which gives rise to the Fraunhofer lines taking place in one thin layer is disproved, the more certain it must be that it represents the integrated effect of several layers. Hence this special examination of the 1893 photographs, to which I am now directing attention, to see if there were any indications as to the localisation of the absorbing vapours which are not represented in the base of the chromosphere.

It will be noted that the evidence is distinctly in favour of such localisation *above* the chromosphere.

But the matter is so important that it must not be allowed to rest here, while photographs with higher dispersion are possible. Hence, then, future eclipse results must be carefully studied from this point of view.

The Chemical Constitution of the Sun's Atmosphere.

The results obtained with regard to the chemistry of the sun will, of course, depend upon the results of the accurate measurement of the coronal rings; of the arcs, both long and short, obtained in the prismatic cameras; and of the lines—true images of the slit—in slit spectroscopes, these measurements have for their object the determination of the wave-lengths of the radiations, so that they can be compared with the wave-lengths of terrestrial substances observed in the laboratory.

The dispersion employed in 1893 was only moderate as compared with that now used in laboratory work, though it was far greater than any employed in eclipse observations before. The double dispersion proposed for 1898 will necessitate additional precaution against error, and in return it may land us in new discoveries. To show that this remark is justified, I will first refer to the method employed in the determination of wave-lengths in the case of the photographs of the 1893 and 1896 eclipses.

The wave-lengths are expressed on Rowland's scale. In the region less refrangible than K, they have been determined from the African photographs, by comparison with the spectrum of Arcturus and other stars photographed with the same instrument, the wave-lengths of the lines in which were determined by reference to Rowland's photographic map The spectrum of Arcturus is almost identical with that of the sun, so that the comparison lines were sufficiently numerous for the purpose. Stars like Bellatrix were employed as an additional check in the case of bright lines not coincident with prominent Fraunhofer lines.

Micrometric measurements of the lines were also made and reduced to wave-lengths in the usual way, by means of a curve; these furnished a check on the general accuracy. In the case of the Brazilian negatives wave-lengths were determined by

means of micrometric measures and a curve, and checked by direct comparisons with a solar spectrum, photographed with the same spectroscope while it was temporarily provided with a slit and collimator. For the reduction of the ultra-violet, in both series of photographs the wave-lengths of the hydrogen lines have been assumed as far as H_{ϕ} from those given by Hale,[1] with the exception of H_{υ}, which falls sufficiently near the calculated wave-length to be accepted as a hydrogen line.

With these as datum lines, wave-length curves were constructed, and the wave-lengths of the other lines found by interpolation.

The wave-lengths of the radiations more refrangible than H_{ζ} were determined from extrapolation curves, so that the degree of accuracy is necessarily less than in the case of the remaining lines.

The scale of intensities adopted is such that 10 represents the brightest lines and 1 the faintest. This facilitates comparisons with Young's well-known list of chromospheric lines, in which 100 represents the maximum frequency and brightness. The intensities have been estimated by taking the strongest line in each negative as 10, irrespective of length of exposure.

This much being premised, let us next consider the thing that is actually measured. If we study eclipse photographs, or such reproductions as have been given in Figs. 12 and 13 of the results obtained in 1893, it will be clear in a moment that the arcs are of different widths because some of the vapours and gases extend further above the photosphere, and therefore above the dark moon which covers it during an eclipse, than others. Obviously, then, we must not take the *centre of the arc.* It is also obvious that we must not take that edge further from the dark moon. If we did either of these things, the positions

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[1] *Ast. and Ast. Phys.*, 1892, pp 50, 602, 618.

of the lines thus recorded would depend not only on the wave-length of the radiations of the vapours and gases which produced them, but also upon the thickness of the vapours.

If, however, we take the edge of the arc at the moon's edge in every case, we shall have a series of numbers involving wave-length only, *except under two conditions*, and this is a very important exception.

The first condition which may vitiate the determination of wave-length in this way is that some of the vapours or gases producing certain lines may be in movement sufficiently rapid along the line of sight to change the wave-lengths of the lines according to a well-known law. Suppose, for instance, we have a stream of iron vapour moving at the rate of fifty miles a second towards the eye through a mass of hydrogen at rest; the lines of the iron spectrum will be shifted towards the violet part of the spectrum, while those of hydrogen will be in their normal position. The higher the dispersion employed the more carefully must such matters as this be studied. This cause, in fact, will, in the case of very violent motion, change even the forms of the prominences.

The forms of monochromatic images of the prominences being produced in part by the movement in the line of sight of the vapours which give rise to them, regions in which the vapours are approaching the earth will be displaced to the more refrangible side of their true positions with respect to the sun's limb, and in the case of receding vapours there would be displacements towards the less refrangible end. Such distortions can be determined, if they exist, by comparing the monochromatic images with those photographed at the same time with the coronagraph. For this purpose, in dealing with the eclipse of 1893 a photograph of the eclipsed sun was enlarged to exactly the same size as the K ring shown in Fig. 46, and the comparison could be made very exactly by fitting a negative of one to a positive of the other. No differences of form, however, could

be detected, so that the velocities in the line of sight must have been comparatively small. Movements across the line of sight will not affect the forms of the monochromatic images of the prominences.

This is a true physical origin of the change of wave-length which may be detected in eclipse photographs; but there is a second, as I have hinted. This, although only an apparent change, has to be reckoned with, since, on the one hand, it may be very misleading, while, on the other, if properly dealt with, it may furnish us with new knowledge.

I have already pointed out that in the determination of the wave-length of the arcs in the prismatic camera photographs, the edge of the line nearest to the dark moon must be measured, rather than the other edge or the middle of the arc. But this assumes that all the arcs really rest on the dark moon. *It is possible, however, that some of them do not extend down to it—that they represent real upper layers.* This has already been pointed out on page 125, and in this case the wave-length obtained by a reference to the dark moon will not be the true one, and, by some means or another, it will have to be corrected. This, though a difficult problem, does not seem an impossible one.

Eclipse Work in Relation to the Dissociation Hypothesis.

In the course of the spectroscopic solar investigations which have been going on since 1868, I have had to point out over and over again that the phenomena observed could be more easily explained on the hypothesis that the chemical elements with which we are familiar here were broken up by the great heat of the sun into simpler forms than in the ordinary one, that the "elements" as we deal with them in laboratories, are incapable of simplification, that is that they are indestructible.

The recent work on the enhanced lines of several of the metallic elements really enables us to predict what we shall

obtain in the Indian eclipse if the dissociation hypothesis be true.

With regard especially to the bearing of the 1893 work on this view, I may state that it is entirely in its favour. The preliminary discussion of individual substances has further abundantly shown that although some of the lines belonging to any particular metal may appear as dark lines in the solar spectrum on account of absorption by the chromosphere, other lines of the same substance are only represented among the dark lines because of absorption taking place elsewhere. This again is an indication of the stratification of the sun's absorbing atmosphere, which, if it exists, must furnish a very strong argument in favour of the dissociation of metallic vapours at solar temperatures. In fact, the eclipse phenomena have been found to be as *bizarre*, in relation to the non-dissociation hypothesis, as those which I have already discussed in relation to observations of sun-spots, chromosphere and prominences made on the uneclipsed sun.

The Italian observations of the quiet solar atmosphere and the Kensington observations of sun-spots have already been especially mentioned. Not only is there no correspondence in the intensity of the lines observed, but the variation in the sun-spot spectrum from maximum to minimum is enormous, while the Fraunhofer lines remain constant.

The view I expressed in 1879,[1] and to which I adhere, is therefore strengthened by the eclipse work. I then wrote:—

"The discrepancy which I pointed out six years ago, between the solar and terrestrial spectra of calcium is not an exceptional, but truly a typical, case. Variations of the same kind stare us in the face when the minute anatomy of the spectrum of almost every one of the so-called elements is studied. If, therefore, the arguments for the existence of our terrestrial elements in extra-terrestrial bodies, including the sun, is to depend upon the perfect matching of the wave-lengths and intensities of the metallic and Fraunhofer lines, then we are driven to the conclusion that the elements with which we are acquainted here do not exist in the sun."

[1] *Roy. Soc. Proc.*, 1879, vol. xxviii, p. 13.

Eclipse Work in Relation to Stellar Physics.

Eclipse results once obtained are not limited to the sun, they find their application in the study of every star in the heavens. It is, indeed, now recognised that observations of eclipses, such as those made in 1893 and 1896, provide us with a series of facts with which to approach the question of the absorption phenomena presented by the stars, and the whole question of the classification of stars depends almost absolutely upon their absorption phenomena.

It is in connection with such inquiries as these, embracing all the suns in the heavens, that the study of the conditions of our own sun's atmosphere becomes of supreme importance. It is obvious that a knowledge of them must be of the utmost value in enabling us to apply a well-established series of facts, gathered in the case of the star nearest to us, to the phenomena presented by the more distant bodies.

In many of these bodies the atmosphere may be millions of miles high; in each star the chemical substances in the hottest and coolest portions may be vastly different; the region, therefore, in which the absorption takes place which, spectroscopically, enables us to discriminate star from star, must be accurately known before we can obtain the greatest amount of information from our inquiries.

If we are justified in arguing from a star with a photosphere as well developed as that of the sun to one in which it is in all probability much less marked in consequence of a much higher temperature, then we must consider that the absorptions which define the various star groups are more conditioned by the temperatures of the hottest regions merely than by the thickness of the absorbing atmospheres, or by the densities of the various vapours. Another consideration to be borne in mind is that if the atmospheres are in part composed of condensable vapours, and not entirely of gases permanent at all stellar temperatures,

condensation must always be going on outside in the reigon of lowest temperature.

On these and other kindred points eclipse observations and eclipse observations only can provide us with more light.

CONCLUSION.

In the foregoing notes no attempt has been made to deal with all the problems which await solution during eclipses.

It is obvious that the aim of those who observe in India next year with the view of advancing the more important problems of physics and chemistry presented to us by the eclipsed sun, should work along the new lines with a view of testing the soundness of the conclusions so far arrived at, and of obtaining new knowledge. I cannot, I think, more fitly close this little book than by giving a very brief summary of the conclusions arrived at in the observation of 1893, so that the drift of much of the work that will be undertaken in 1898 may be gathered.

(1) With the prismatic camera, photographs may be obtained with short exposures, so that the phenomena can be recorded at short intervals during the eclipse.

(2) The most intense images of the prominences are produced by the H and K radiations of calcium. Those depicted by the rays of hydrogen and helium are less intense, and do not reach to so great a height.

(3) The forms of the prominences photographed in monochromatic light (H and K) during the eclipse of 1893, do not differ sensibly from those photographed at the same time with the coronagraph.

(4) The undoubted spectrum of the corona, in 1893, consisted of seven rings besides that due to 1474 K.

The evidence that these belong to the corona is absolutely conclusive. It is probable that they are only represented by feeble lines in the Fraunhofer spectrum, if present at all.

(5) All the coronal rings recorded were most intense in the brightest coronal regions near the sun's equator, as depicted by the coronagraph

(6) The strongest coronal line, 1474 K, is not represented in the spectrum of the chromosphere and prominences, while H and K do not appear in the spectrum of the corona, although they are the most intense radiations in the prominences.

(7) A comparison of the results with those obtained in previous eclipses confirms the idea that 1474 K is brighter at the maximum than at the minimum sun-spot period.

(8) Hydrogen rings were not photographed in the coronal spectrum of 1893.

(9) D_3 was absent from the coronal spectrum of 1893, and reasons are given which suggest that its recorded appearance in 1882 was simply a photographic effect due to the unequal sensitiveness of the isochromatic plate employed.

(10) There is distinct evidence of periodic changes of the continuous spectrum of the corona

(11) Many lines hitherto unrecorded in the chromosphere and prominences were photographed by the prismatic cameras.

(12) The preliminary investigation of the chemical origins of the chromosphere and prominence lines enables us to state generally that the chief lines are due to calcium, hydrogen, helium, strontium, iron, magnesium, manganese, barium, chromium, and aluminium. None of the lines appear to be due to nickel, cobalt, cadmium, tin, zinc, silicon, or carbon.

(13) The spectra of the chromosphere and prominences become more complex as the photosphere is approached.

(14) In passing from the chromosphere to the prominences some lines become relatively brighter, but others dimmer. The same line sometimes behaves differently in this respect in different prominences.

(15) The prominences must be fed from the outer parts of the

solar atmosphere, since their spectra show lines which are absent from the spectrum of the chromosphere.

(16) The absence of the Fraunhofer lines from the integrated spectra of the solar surroundings and uneclipsed photosphere shortly after totality need not necessarily imply the existence of a reversing layer.

(17) The spectrum of the base of the sun's atmosphere, as recorded by the prismatic camera contains only a small number of lines as compared with the Fraunhofer spectrum. Some of the strongest bright lines in the spectrum of the chromosphere are not represented by dark lines in the Fraunhofer spectrum, and some of the most intense Fraunhofer lines were not seen bright in the spectrum of the chromosphere The so-called "reversing layer" is, therefore, incompetent to produce the Fraunhofer spectrum by its absorption

(18) Some of the Fraunhofer lines are produced by absorption taking place in the chromosphere, while others are produced by absorption at higher levels.

(19) The eclipse work strengthens the view that chemical substances are dissociated at solar temperatures.

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